



# **Managing the Nuclear Fuel Cycle: Policy Implications of Expanding Global Access to Nuclear Power**

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## Summary

After several decades of widespread stagnation, nuclear power is attracting renewed interest. New license applications for 30 reactors have been announced in the United States, and another 160 are under construction or planned globally. In the United States, interest appears driven, in part, by tax credits, loan guarantees, and other incentives in the 2005 Energy Policy Act, as well as by potential greenhouse gas controls that may increase the cost of fossil fuels. Moreover, the U.S. Department of Energy is spending several hundred million dollars per year to develop the next generation of nuclear power technology.

Expanding global access to nuclear power, nevertheless, has the potential to lead to the spread of nuclear technology that could be used for nuclear weapons. Despite 30 years of effort to limit access to uranium enrichment, several undeterred states pursued clandestine nuclear programs, the A.Q. Khan black market network's sales to Iran and North Korea representing the most egregious examples. Concern over the spread of enrichment and reprocessing technologies, combined with a growing consensus that the world must seek alternatives to dwindling and polluting fossil fuels, may be giving way to optimism that advanced nuclear technologies may offer proliferation resistance.

Proposals offering countries access to nuclear power and thus the fuel cycle have ranged from a formal commitment by these countries to forswear sensitive enrichment and reprocessing technology, to a de facto approach in which a state would not operate fuel cycle facilities but make no explicit commitment, to no restrictions at all. Countries joining the U.S.-led Global Nuclear Energy Partnership (GNEP) signed a statement of principles that represented a shift in U.S. policy by not requiring participants to forgo domestic fuel cycle programs. Whether developing states will find existing proposals attractive enough to forgo what they see as their "inalienable" right to develop nuclear technology for peaceful purposes remains to be seen.

GNEP has continued as an international forum under the Obama Administration, but the Bush Administration's plans for constructing nuclear fuel reprocessing and recycling facilities in the United States have been halted. Instead, the Obama Administration is supporting fundamental research on a variety of potential waste management technologies. Other ideas for limiting the expansion of nuclear fuel cycle facilities include placing all enrichment and reprocessing facilities under multinational control, developing new nuclear technologies that would not produce weapons-usable fissile material, and developing a multinational waste management system. Various systems of international fuel supply guarantees, multilateral uranium enrichment centers and nuclear fuel reserves have also been proposed.

Congress will have a considerable role in at least four areas of oversight related to fuel cycle proposals. The first is providing funding and oversight of U.S. domestic programs related to expanding nuclear energy in the United States. The second area is policy direction and/or funding for international measures to assure supply. A third set of policy issues may arise in the context of implementing the international component of GNEP or related initiatives. A fourth area in which Congress plays a key role is in the approval of nuclear cooperation agreements. Significant interest in these issues is expected to continue in the second session of the 111<sup>th</sup> Congress.

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## Introduction

Renewed interest in expanding the role of nuclear power in meeting world energy demand has also led to increased concerns about limiting the spread of nuclear weapons-relevant technology. Most of this concern focuses on the nuclear fuel cycle, which includes facilities that can be used to make fuel for nuclear reactors or materials for weapons.

After languishing for several decades, nuclear power in the United States appears poised for new growth, with license applications announced for up to 30 new commercial reactors. Two new U.S. uranium enrichment plants are currently under development in anticipation of an increased demand for nuclear fuel. However, no U.S. facilities are currently planned for reprocessing spent nuclear fuel—the separation of uranium and plutonium to make new fuel. Other countries provide commercial reprocessing services and, with several notable exceptions, have kept their commercial and weapons fuel cycles separate.

To reduce the likelihood that nuclear fuel cycle facilities could be used for weapons programs, several proposals have been made in recent years to discourage additional countries from developing uranium enrichment and reprocessing capability. Because a major justification for such facilities is to ensure fuel supplies for a nation's nuclear power plants, proposals to discourage fuel cycle facilities have focused on various alternative ways to guarantee supplies of nuclear fuel. These ideas have ranged from guaranteed access to foreign fuel cycle facilities to the establishment of nuclear fuel stockpiles, or "banks," under international control.

Under the Bush Administration, the U.S. Department of Energy (DOE) considered nuclear power to be "the only proven technology that can provide abundant supplies of base-load electricity reliably and without air pollution or emissions of greenhouse gases."<sup>1</sup> The National Energy Policy Development Group recommended in 2001 that President Bush "support the expansion of nuclear energy in the United States as a major component of our national energy policy." About the same time, DOE created the Generation IV International Forum to collaborate with 10 other states in investigating "innovative nuclear energy system concepts for meeting future energy challenges." Congress has since appropriated hundreds of millions of dollars to support several programs related to the development of new nuclear power plants in the United States, including the Advanced Fuel Cycle Initiative and Generation IV. In passing the Energy Policy Act of 2005, Congress created new federal incentives for nuclear power plant construction. In February 2006, the Secretary of Energy announced the Global Nuclear Energy Partnership (GNEP) as part of President Bush's Advanced Energy Initiative.

GNEP has continued as an international forum under the Obama Administration, but the Bush Administration's plans for constructing nuclear fuel reprocessing and recycling facilities in the United States have been halted. Instead, the Obama Administration is supporting fundamental research on a variety of potential waste management technologies.

Concerns about the nuclear fuel cycle have been increased by several high-profile cases of subversion of ostensibly commercial uranium enrichment and reprocessing technologies for military purposes. In 2003 and 2004, it became evident that Pakistani nuclear scientist A.Q. Khan had sold sensitive technology and equipment related to uranium enrichment—a process that can

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<sup>1</sup> U.S. Department of Energy, "The Global Nuclear Energy Partnership," Factsheet 06-GA50506-01

be used to make fuel for nuclear power and research reactors, or to make fissile material for nuclear weapons—to states such as Libya, Iran, and North Korea. Although Pakistan’s leaders maintain they did not acquiesce in or abet Khan’s activities, Pakistan remains outside the Nuclear Nonproliferation Treaty (NPT) and the Nuclear Suppliers Group (NSG). Iran has been a direct recipient of Pakistani enrichment technology.<sup>2</sup>

The Board of Governors of the International Atomic Energy Agency (IAEA) found in 2005 that Iran’s breach of its safeguards obligations constituted noncompliance with its safeguards agreement, and referred the case to the United Nations Security Council in February 2006. Despite repeated calls by the U.N. Security Council for Iran to halt enrichment and reprocessing-related activities, and imposition of sanctions, Iran continues to develop its enrichment capability.<sup>3</sup> Iran insists on its inalienable right to develop peaceful uses of nuclear energy, pursuant to Article IV of the NPT. Interpretations of this right have varied over time.<sup>4</sup> IAEA Director General Mohamed El Baradei has not disputed this inalienable right and, by and large, neither have U.S. government officials. However, the case of Iran raises perhaps the most critical question in this decade for strengthening the nuclear nonproliferation regime: How can access to sensitive fuel cycle activities (which could be used to produce fissile material for weapons) be circumscribed without further alienating non-nuclear-weapon states in the NPT?

Leaders of the international nuclear nonproliferation regime have suggested ways of reining in the diffusion of such inherently dual-use technology, primarily through the creation of incentives not to enrich uranium or separate plutonium. The international community is in the process of evaluating those proposals and may decide upon a mix of approaches.

Most of the proposals are not new, but rather variations of those developed 30 or more years ago.<sup>5</sup> In the 1970s, efforts to limit or manage the spread of nuclear fuel cycle technologies for nonproliferation reasons foundered for technical and political reasons, but many states were nevertheless deterred from enrichment and reprocessing simply by the high technical and financial costs of developing sensitive nuclear technologies, as well as by a slump in the nuclear market. Several developments may now make efforts to limit access to the nuclear fuel cycle more feasible and timely: a growing concern about the spread of enrichment technology (specifically via the A.Q. Khan black market network, as well as Iran’s efforts); a growing consensus that the world must seek alternatives to polluting fossil fuels; and optimism about new nuclear technologies that may offer more proliferation-resistant systems. Central to the debate is developing proposals attractive enough to compel states to forgo what they see as their inalienable right to develop nuclear technology for peaceful purposes.

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<sup>2</sup> See also CRS Report RL34248, *Pakistan’s Nuclear Weapons: Proliferation and Security Issues*, by Paul K. Kerr and Mary Beth Nikitin.

<sup>3</sup> “Security Council, in Presidential Statement, Underlines Importance of Iran’s Re-Establishing Full, Sustained Suspension of Uranium Enrichment Activities,” March 29, 2006, at <http://www.un.org/News/Press/docs/2006/sc8679.doc.htm>, and U.N. Security Council Resolution 1737 (2006) <http://www.un.org/News/Press/docs/2006/sc8928.doc.htm>.

<sup>4</sup> Most observers point to the obligation in Article IV that such pursuit must be consistent with a state’s obligations under Articles II and III of the treaty. Article II refers to a state’s obligation to forswear nuclear weapons development and Article III refers to a state’s obligation to undertake safeguards “for the exclusive purpose of verification of the fulfillment of its obligations” under the treaty.

<sup>5</sup> See timeline of fuel cycle proposals, available at [http://www.iaea.org/NewsCenter/Focus/FuelCycle/key\\_events.shtml](http://www.iaea.org/NewsCenter/Focus/FuelCycle/key_events.shtml).

At the same time, there is debate on how to improve the IAEA safeguards system and its means of detecting diversion of nuclear material to a weapons program in the face of a worldwide nuclear power expansion.

This report is intended to provide Members and congressional staff with the background needed to understand the current debate over proposed strategies to redesign the global nuclear fuel cycle. It begins with a look at the motivating factors underlying the resurgent interest in nuclear power, the nuclear power industry's current state of affairs, and the interdependence of the various stages of the nuclear fuel cycle. A number of proposals have been offered that are aimed at limiting direct participation in the global nuclear fuel industry by assuring access to nuclear fuel supplies:

Year	Agency	Proposal
2003	IAEA	Would establish internationally owned fuel cycle centers.
2004	United States	Would keep uranium enrichment and plutonium reprocessing in the hands of current technology holders, while providing fuel guarantees to those who abandon the option.
2005	IAEA	Explored a variety of options to address front end and back end problems and their attractiveness to different groups of states, and surveyed past proposals.
2005	Russian Federation	Would establish international fuel cycle centers.
2006	United States	U.S. Global Nuclear Energy Partnership originally proposed that certain recognized fuel cycle countries would ensure reliable supply to the rest of the world in return for commitments to renounce enrichment and reprocessing; also proposed solutions for recycling of spent fuel and storage issues.
2006	U.S., U.K., Russia, France, Germany, and Netherlands	Six Country Concept would establish reliable access to nuclear fuel.
2006	Nuclear Threat Initiative	Promised \$50 million for an international nuclear fuel bank under IAEA supervision provided another \$100 million donated within two years and IAEA organizes implementation.
2007	United States	Revised GNEP would promote an international nuclear fuel supply framework (without explicit renunciation of fuel technology) to reduce proliferation risk and a closed fuel cycle featuring recycling techniques that do not separate plutonium.

## Renewed Interest in Nuclear Power Expansion<sup>6</sup>

Commercializing nuclear power has proved far more challenging than first envisioned. World nuclear capacity had reached about 200 gigawatts during the 1980s, but as confidence in nuclear power safety declined after accidents at Three Mile Island and Chernobyl, the rate of further capacity additions fell more than 75% during the following decade.<sup>7</sup> Today, nuclear power plants have a total capacity of about 373 gigawatts—providing about 15% of the world's electricity generation. Though a significant amount, it is far less than that projected 50 years ago. High construction and operating costs, safety problems and accidents, and controversy over nuclear waste disposal slowed the worldwide growth of nuclear power.

<sup>6</sup> This section was prepared by Mark Holt, Specialist in Energy Policy, and Anthony Andrews, Specialist in Energy Policy, in the Resources, Science, and Industry Division, Congressional Research Service.

<sup>7</sup> International Energy Agency, *World Energy Outlook 2006*, p. 349.



With uranium once considered a scarce resource, reprocessing and fast breeder technology was promised as a means of extending the energy remaining in spent nuclear fuel. In the 1980s, as the economics of advanced nuclear technology became questionable with declining fossil fuel prices and increased uranium supplies, national programs to develop fast breeder reactors came nearly to a standstill. Moreover, the plutonium fuel produced by breeder reactors drew strong opposition over its potential use in nuclear weapons.

In the past few years, however, the original promises of nuclear power have attracted renewed interest around the world. What has changed?

Volatile prices for oil and natural gas are a fundamental factor in national energy policymaking. Average world prices for a barrel of oil rose from below \$10 at the beginning of 1999 to above \$130 in mid-2008. They then declined to around \$50 in early 2009 and rose to around \$75 by early 2010.<sup>8</sup> U.S. natural gas prices have followed a similar track, along with prices of U.S. exports and imports.<sup>9</sup> As a result, national governments are searching for alternative energy sources, often including nuclear power. However, only 20% of the world's electricity generation is fueled by natural gas and 7% by oil (the majority of the world's electricity is generated from coal),<sup>10</sup> so nuclear power's ability to directly substitute for oil and gas is limited, at least in the near term.

For nuclear power to have a significant impact on oil demand, long-term changes in energy-use patterns would have to take place, particularly in the transportation sector. One possibility is that nuclear power plants could be used to produce hydrogen, which could provide energy for fuel-cell vehicles. The U.S. Department of Energy has been developing processes that could produce hydrogen in a high-temperature reactor, an effort that has continued under the Obama Administration. Another possibility is the commercialization of all-electric or plug-in hybrid vehicles that could be recharged with nuclear-generated electricity. But even if such technologies were to be successfully developed, it would take many years for the new vehicles and, in the case of hydrogen, fuel delivery infrastructure to have a significant energy impact.

Government policies aside, volatile oil and gas prices are heightening interest in nuclear power by improving current projections of nuclear power's economic viability. In the United States, natural gas has been the overwhelming fuel of choice for new electrical generation capacity since the early 1990s, although coal-fired plants still generate nearly half of U.S. electricity (and 40% of world electricity<sup>11</sup>). Because fuel costs constitute a relatively small percentage of nuclear power costs, higher natural gas prices could make new nuclear power plants economically competitive, despite higher uranium prices.<sup>12</sup>

Growing worldwide concern about greenhouse gas emissions, particularly carbon dioxide from fossil fuels, has renewed attention to nuclear power's lack of direct CO<sub>2</sub> emissions. President Obama's 2010 State of the Union address explicitly included "a new generation of safe, clean nuclear plants" as part of the Administration's energy and environmental strategy. Policies to reduce greenhouse gas (GHG) emissions may also indirectly encourage nuclear power expansion

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<sup>8</sup> Energy Information Administration, at <http://tonto.eia.doe.gov/dnav/pet/hist/wtotworldw.htm>.

<sup>9</sup> EIA, <http://www.eia.doe.gov/emeu/international/gasprice.html>

<sup>10</sup> World Energy Outlook, *op. cit.*, pp. 139, 141.

<sup>11</sup> World Energy Outlook, *op. cit.*, p. 140.

<sup>12</sup> CRS Report RL33442, *Nuclear Power: Outlook for New U.S. Reactors*, by Larry Parker and Mark Holt.

by increasing the cost of electricity from new fossil-fuel-fired power plants above that of nuclear power plants.

Some support for using nuclear power to reduce GHG emissions has emerged in academic and think-tank circles. As stated by the Massachusetts Institute of Technology in its major study *The Future of Nuclear Power*: “Our position is that the prospect of global climate change from greenhouse gas emissions and the adverse consequences that flow from these emissions is the principal justification for government support of the nuclear energy option.”<sup>13</sup> But environmental groups generally contend that the nuclear accident, waste, and weapons proliferation risks posed by nuclear power outweigh any GHG benefits. The large construction expenditures required by commercial reactors, they contend, would yield greater GHG reductions if used for energy efficiency and renewable generation. Finally, they note that nuclear power, while not directly emitting greenhouse gases, produces indirect emissions through the nuclear fuel cycle and during plant construction.

Another key factor behind the renewed interest in nuclear power is the improved performance of existing reactors. U.S. commercial reactors generated electricity at an average of 90% of their total capacity in 2008,<sup>14</sup> after averaging around 75% in the mid-1990s and around 65% in the mid-1980s. Worldwide performance has seen similar improvement.<sup>15</sup> The improved operation of nuclear power plants has helped drive down the cost of nuclear-generated electricity. Average U.S. reactor operations and maintenance costs (including fuel but excluding capital costs) dropped steadily from a high of about 3.5 cents/kilowatt-hour (kwh) in 1987 to below 2 cents/kwh in 2001 (in 2001 dollars).<sup>16</sup> U.S. nuclear plant operating costs during 2006-2008 averaged about 1.9 cents/kwh.<sup>17</sup>

Nuclear interest has been further increased in the United States by incentives in the Energy Policy Act of 2005 (P.L. 109-58). The law provides a nuclear energy production tax credit for up to 6,000 megawatts of new nuclear capacity, compensation for regulatory delays for the first six new reactors, and federal loan guarantees for nuclear power and other advanced energy technologies. Under certain baseline assumptions, the tax credits and loan guarantees could determine whether new U.S. nuclear plants would be economically viable.<sup>18</sup>

U.S. electric utilities and other companies during the past two years have announced plans to submit license applications to the Nuclear Regulatory Commission (NRC) for about 30 new commercial reactors (see **Table 1**.) NRC has issued “early site permits”—which resolve site-related issues for possible future reactor construction—at locations in Illinois, Mississippi, Virginia, and Georgia. The Tennessee Valley Authority in 2007 restarted construction of its long-delayed Watts Bar 2 reactor, which had been ordered in 1970. But despite that flurry of activity, no new reactor orders have been formally placed. No reactors have been ordered in the United States since 1978, and all orders after 1973 were subsequently cancelled.

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<sup>13</sup> Interdisciplinary MIT Study, *The Future of Nuclear Power*, Massachusetts Institute of Technology, 2003, p. 79.

<sup>14</sup> “World Nuclear Performance in 2008 Close to Output in 2007,” *Nucleonics Week*, March 5, 2009, p. 1.

<sup>15</sup> *Nuclear Engineering International*, November 2005, p. 37.

<sup>16</sup> Uranium Information Centre, *The Economics of Nuclear Power*, Briefing Paper 8, January 2006, p. 3.

<sup>17</sup> “U.S. Utility Operating Costs, 2008,” *Nucleonics Week*, December 24, 2009.

<sup>18</sup> CRS Report RL34746, *Power Plants: Characteristics and Costs*, by Stan Mark Kaplan.

The recent nuclear plant license applicants have not committed to building new reactors if the licenses are approved, but the sponsors of four of the proposed nuclear projects have signed preliminary engineering, procurement, and construction (EPC) contracts. President Obama announced a conditional loan guarantee on February 16, 2010, for two proposed reactors at Georgia's Vogtle nuclear power plant, which had previously received an NRC early site permit. On the other hand, Entergy suspended further license review of its planned GE ESBWR reactors at River Bend, LA, and Grand Gulf, MS, and Dominion is seeking other potential vendors for its planned ESBWR at North Anna, VA, although it is continuing with the licensing process. AmerenUE has suspended construction plans for a new reactor at its Callaway plant, while also continuing with NRC licensing.

**Table I. Announced Nuclear Plant License Applications**

<b>Announced Applicant</b>	<b>Site</b>	<b>Planned Application</b>	<b>Reactor Type</b>	<b>Units</b>	<b>Status</b>
Alternate Energy	Hammett (ID)	2009	Areva EPR	1	
AmerenUE	Callaway (MO)	Submitted 7/24/08	Areva EPR	1	Construction plans suspended 4/23/09; NRC license review suspended 6/23/09
Amarillo Power	Near Amarillo (TX)	2009	Areva EPR	2	
Dominion	North Anna (VA)	Submitted 11/27/07	GE ESBWR	1	Other reactor vendors being considered 1/9/09
DTE Energy	Fermi (MI)	Submitted 9/18/08	GE ESBWR	1	
Duke Energy	Cherokee (SC)	Submitted 12/13/07	Westinghouse AP1000	2	
Entergy	River Bend (LA)	Submitted 9/25/08	Not specified	1	Licensing suspended 1/9/09
Luminant Power (formerly TXU)	Comanche Peak (TX)	Submitted 9/19/08	Mitsubishi US-APWR	2	
FPL	Turkey Point (FL)	Submitted 6/30/09	Westinghouse AP1000	2	
NRG Energy	South Texas Project	Submitted 9/20/07	GE ABWR	2	EPC contract signed with Toshiba 2/12/09
NuStart	Grand Gulf (MS), Entergy	Submitted 2/27/08	Not specified	1	Licensing suspended Jan. 9, 2009
	Bellefonte (AL), TVA	Submitted 10/30/07	Westinghouse AP1000	2	NuStart announced shift of lead unit to Vogtle 4/30/09
PPL	Bell Bend (PA)	Submitted 10/10/08	Areva EPR	1	
Progress Energy	Harris (NC)	Submitted 2/19/08	Westinghouse AP1000	2	EPC contract signed 1/5/09
	Levy County (FL)	Submitted 7/30/08	Westinghouse AP1000	2	
SCE&G	Summer (SC)	Submitted 3/31/08	Westinghouse	2	EPC contract signed

Announced Applicant	Site	Planned Application	Reactor Type	Units	Status
			API000		5/27/08
Southern	Vogtle (GA)	Submitted 3/31/08	Westinghouse API000	2	EPC contract signed 4/8/08; Vogtle to be NuStart lead unit; NRC granted early site permit 8/26/09; conditional DOE loan guarantee announced 2/16/10
UniStar (Constellation Energy and EDF)	Calvert Cliffs (MD)	Submitted 7/13/07 (Part 1), 3/13/08 (Part 2)	Areva EPR	1	
	Nine Mile Point (NY)	Submitted 9/30/08	Areva EPR	1	Licensing suspended 12/1/09
<b>Total Units</b>				<b>29</b>	

**Sources:** NRC, *Nucleonics Week*, *Nuclear News*, Nuclear Energy Institute, company news releases.

New reactors are on order elsewhere in the world, and several non-nuclear countries have announced that they are considering the nuclear option. As **Figure 2** shows, the vast majority of reactors currently under construction are in Asia, with only a handful in the rest of the world.

Despite the recent positive developments for nuclear power, much uncertainty still remains about its prospects. Construction costs for new nuclear power plants—which were probably the dominant factor in halting the first round of nuclear expansion—continue to loom as a potential insurmountable obstacle to renewed nuclear power growth. Average U.S. nuclear plant construction costs more than doubled from 1971 to 1978, according to the Office of Technology Assessment, and nearly doubled again by the mid-1980s, not including interest accrued during construction.<sup>19</sup> Including interest, many U.S. nuclear plants proved to be grossly uneconomic, often with capital costs totaling more than \$3,000 per kilowatt of capacity in 2000 dollars,<sup>20</sup> and relying on the utility regulatory system to recover their costs.

Major reactor vendors, such as General Electric and Westinghouse, have contended that new designs and construction methods will cut costs of future reactors considerably. However, recent projected costs for new reactors average \$3,900 per kilowatt, excluding interest, making them potentially more expensive than the previous generation of reactors.<sup>21</sup> Capital costs of competing power generation technologies, particularly coal, have also risen in recent years.

New U.S. nuclear plants may be helped by a new NRC licensing process that is intended to avoid some of the regulatory problems that delayed completion of some reactors in the past. Current reactor applications listed in **Table 1** are being evaluated by NRC under the new system, but no licenses under the new system have yet been issued.

<sup>19</sup> Office of Technology Assessment, *Nuclear Power in an Age of Uncertainty*, OTA-E-216, February 1984, p. 59.

<sup>20</sup> Jan Willem Storm van Leeuwen and Philip Smith, *Nuclear Energy, the Energy Balance*, July 31, 2005, Chapter 3, p. 2.

<sup>21</sup> CRS Report RL34746, *Power Plants: Characteristics and Costs*, by Stan Mark Kaplan, Table B-3.

Many other important factors in the future of nuclear power are similarly uncertain. Prices of competing fuels, particularly natural gas, have risen recently but have been volatile in the recent past. If fossil fuel prices become depressed for a sustained period, as in the late 1980s through the 1990s, support for nuclear power as an alternative energy source could again be undermined. Major accidents, such as Three Mile Island and Chernobyl, would almost certainly diminish public support for nuclear power. Disposal of high-level nuclear waste, which reprocessing or recycling is intended to address, will continue to generate controversy as governments attempt to develop permanent underground repositories—none of which are yet operating.

## Worldwide Nuclear Power Status

Operating commercial nuclear reactors around the world currently total 436, with total installed electric generating capacity of 372 gigawatts.<sup>22</sup> More than 80% of world nuclear capacity is in member nations of the Organization for Economic Cooperation and Development (OECD), while slightly more than 10% is in Russia and other former nations of the Soviet bloc. The remainder, about 5%, is in developing countries such as China and India. Nuclear power supplied 27.3% of electricity generated in OECD countries and 5.2% in non-OECD countries in 2006.<sup>23</sup>

Unlike the United States, where only one long-deferred reactor is currently under construction, much of the rest of the world has continued building nuclear plants, although at a modest pace. Since 1996, about 40 commercial reactors have started up, an average of about four per year. About 30 reactors were permanently closed during that period, although many of them were smaller than the newly started reactors.<sup>24</sup>

Current reactor construction is dominated by Asia, as shown by **Figure 2**. Of the 53 reactors now under construction around the world, 35 are in Asia, while 13 are in Europe, four in the Americas, and one in the Middle East (Iran). Planned or proposed nuclear power plants show a similar trend. Of the 469 planned or proposed reactors in **Figure 2**, well more than half (254) are in Asia, while 121 are in Europe, 47 in the Americas, and 20 in the Middle East. South Africa has proposed up to 27 new reactors.

The renewed worldwide interest in nuclear power has led to a possible expansion of the technology to currently non-nuclear nations. Nine of the countries that are currently building or formally planning reactor projects—Belarus, Egypt, Indonesia, Iran, Kazakhstan, Thailand, Turkey, the United Arab Emirates, and Vietnam—have never operated nuclear power plants. Several other non-nuclear power countries have proposed building power reactors, including Bangladesh, Israel, and Poland.<sup>25</sup>

## Nuclear Fuel Services Market

The possible upsurge in worldwide nuclear power plant construction has focused new attention on nuclear fuel production. Chronic worldwide overcapacity in all phases of the nuclear fuel cycle appears to be ending, evidenced by higher prices for uranium and enrichment services in

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<sup>22</sup> World Nuclear Association, <http://www.world-nuclear.org/info/reactors.html>.

<sup>23</sup> International Energy Agency, *World Energy Outlook 2008*, pp. 508, 522.

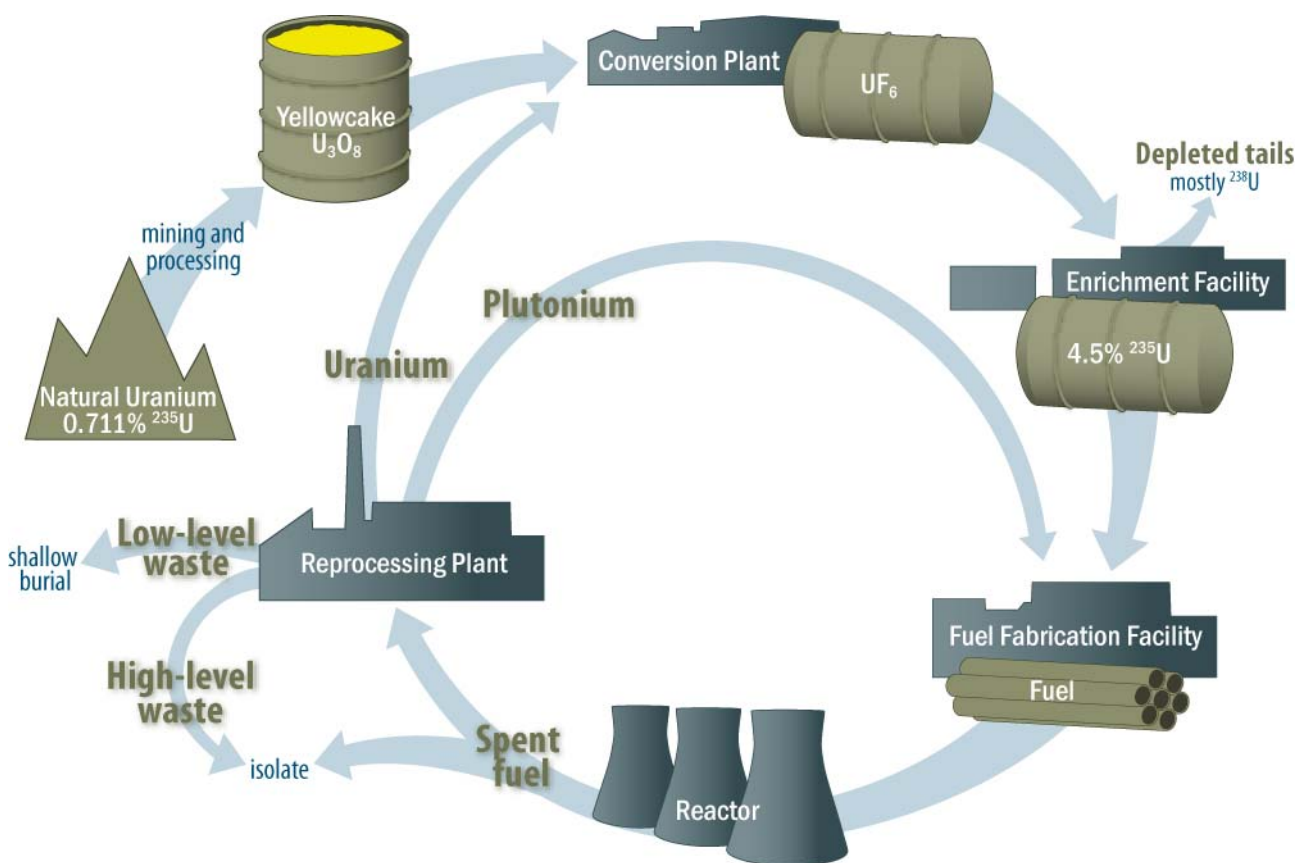
<sup>24</sup> World Nuclear Association Reactor Database, at [http://www.world-nuclear.org/reference/reactorsdb\\_index.php](http://www.world-nuclear.org/reference/reactorsdb_index.php).

<sup>25</sup> World Nuclear Association, <http://www.world-nuclear.org/info/reactors.html>.

recent years. The tightening supplies have sparked plans for new fuel cycle facilities around the world and also renewed concerns about controls over the spread of nuclear fuel technology.

The nuclear fuel cycle begins with mining uranium ore, and upgrading it to yellowcake. Because naturally occurring uranium lacks sufficient fissile  $^{235}\text{U}$  to make fuel for commercial light-water reactors, the concentration of  $^{235}\text{U}$  must be increased several times above its natural level of 0.7% in a uranium enrichment plant. A nuclear power plant operator or utility typically purchases yellowcake and contracts for its conversion to uranium hexafluoride, then enrichment, and finally fabrication into fuel elements (**Figure 1**). Commercial enrichment services are available in the United States, Europe, Russia, and Japan. Fuel fabrication services are even more widely available. While waiting for conversion, the yellowcake remains a fungible commodity that can be consigned by the reactor operator to any conversion plant and the product sent to any enrichment plant (within trade restrictions between countries).<sup>26</sup> The sale of yellowcake had been informal, until recently when it moved to a more formal commodity transaction basis. The various stages of the nuclear fuel cycle are described below.

**Figure 1. The Conceptual Nuclear Fuel Cycle**



<sup>26</sup> IAEA, *Country Nuclear Fuel Cycle Profiles*, 2<sup>nd</sup> ed., 2005.

## Yellowcake

Conventionally mined uranium ore (open-pit and underground) is milled, then acid-leached to extract uranium oxide. The extract is then filtered, dried, and packaged as uranium yellowcake for shipment to a conversion plant. In situ leaching avoids the mechanical mining steps by directly injecting solvents into the ore body through wells drilled from the surface. The dissolved uranium is pumped to the surface, where the uranium oxide is similarly processed into yellowcake for shipment.

U.S. uranium reserves are located in Arizona, Colorado, Nebraska, New Mexico, Texas, Utah, Washington, and Wyoming. According to the Energy Information Administration (EIA), 10 underground mines and six in-situ mines were operating in the United States in 2008, four more than the previous year. EIA reports 53 million pounds of  $U_3O_8$  were purchased for U.S. nuclear power reactors in 2008, of which 14% was U.S. origin.<sup>27</sup> The balance was made up in part by imports and downblended highly enriched uranium (HEU), as discussed further below.

A typical 1,000 MW light water reactor fuel load may require converting and enriching nearly 800,000 lbs of uranium “yellowcake” ( $U_3O_8$ ). Approximately 51,800 metric tons (114 million lbs) of yellowcake was produced worldwide in 2008. Annual worldwide uranium demand is estimated to be about 78,500 metric tons of  $U_3O_8$ . Most of the difference between annual production and demand is covered by sales from former military uranium stockpiles.<sup>28</sup> The International Atomic Energy Agency (IAEA) projects that the demand for uranium will begin to exceed supply after 2010, and by as much as 10,000 metric tons by 2020.<sup>29</sup> IAEA believes that the shortfall could be made up by downblending more HEU released from weapons stockpiles.

Unlike gold or oil commodities, uranium yellowcake had not been offered through a formal market exchange until quite recently. Uranium price indicators had been developed by a small number of private business organizations, such as the World Nuclear Fuel Market (WNFM) and the Ux Consulting Company (UxC), that independently monitor uranium market activities, including offers, bids, and transactions. The price indicators are owned by and proprietary to the businesses that has developed them.

NAC International (now a USEC Inc. subsidiary) established the World Nuclear Fuel Market (WNFM) to provide uranium price information in 1974. The WNFM membership comprises 79 companies representing 18 countries.<sup>30</sup> The WNFM provides the uranium price information system (UPIS) for both Western and Russian yellowcake contract prices.<sup>31</sup> A quarterly UPIS report presents aggregated information based on actual uranium contract price data provided by the 19 UPIS subscribers.<sup>32</sup>

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<sup>27</sup> U.S. DOE Energy Information Administration, <http://www.eia.doe.gov/fuelnuclear.html>.

<sup>28</sup> World Nuclear Association, <http://www.world-nuclear.org/info/inf22.html>.

<sup>29</sup> Note: Metric tons is the unit of measurement for uranium fuel. One metric ton is approximately 2,200 pounds. International Atomic Energy Agency, *Management of high enriched uranium for peaceful purposes: Status and trends* (IAEA-TECDOC-1452), June 2005.

<sup>30</sup> World Nuclear Fuel Market website, at <http://www.wnfm.com/public/default.htm>.

<sup>31</sup> Information on the Uranium Price Information System is available through NAC International at (678) 328-1211 or e-mail at [gleamon@nacintl.com](mailto:gleamon@nacintl.com).

<sup>32</sup> Nine U.S. companies, 10 non-U.S. companies, 12 utilities, four producers, two traders, and one supplier.

The UxC pricing index has been utilized by major nuclear fuel market participants, the federal government, and private business. The UxC yellowcake price was one of only two weekly uranium price indicators that were accepted by the uranium industry, as witnessed by their inclusion in most “market price” sales contracts; that is, sales contracts with pricing provisions that call for the future uranium delivery price to be equal to the market price at or around the time of delivery.

In April 2007, the New York Mercantile Exchange (NYMEX) announced that it had partnered with the UxC to provide financially settled on- and off-exchange traded uranium futures contracts.<sup>33</sup> A NYMEX uranium futures contract’s final settlement price is based on the UxC pricing index for yellowcake. Uranium futures contracts are available for trading on Chicago Mercantile Exchange Globex, and for clearing on NYMEX ClearPort.<sup>34</sup> The size of each contract is 250 lbs, and prices are quoted in U.S. currency. The final settlement price is the spot month-end price published by UxC. A standard contract for trading physical uranium is currently under development.<sup>35</sup>

Uranium is typically mined outside the countries that use it. Nearly 60% of the world’s production in 2008 came from Canada, Kazakhstan, and Australia, while more than half of the world’s commercial reactors are in the United States, France, and Japan.<sup>36</sup> But security of uranium supply, while always an underlying policy concern, has rarely been a real problem, because production vastly outstripped demand during the first three decades of the commercial nuclear power era—until about the mid-1980s.<sup>37</sup> As a result, a huge overhang of military and civilian stockpiles of uranium helped maintain a worldwide buyers’ market.

Since the mid-1980s, however, world nuclear fuel requirements continued to rise while uranium exploration and production fell. By 2000, as U.S. spot-market prices hit bottom (at about \$7 per pound), the western world’s nuclear fuel requirements were twice the level of production. At that point, commercial stockpiles had been drawn down enough to begin putting pressure on U.S. spot prices, which rose slightly through 2003 and then dramatically (above \$75 per pound) in 2007, before falling back to the \$50 range in 2009 and early 2010. The spot price represents about 20% of the market but provides an indicator of future contracts, which usually run three to seven years.<sup>38</sup>

Despite low worldwide exploration expenditures since the mid-1980s caused by oversupply and low prices, estimated uranium resources have trended upward over the long term. As a result, according to the OECD Nuclear Energy Agency (NEA), known conventional resources have averaged 45 years of supply during the past 20 years, despite steadily increasing annual world uranium requirements, currently about 70,000 metric tons. “Taken together the lessons of the past

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<sup>33</sup> New York Mercantile Exchange, at [http://www.nymex.com/UX\\_pre\\_agree.aspx](http://www.nymex.com/UX_pre_agree.aspx).

<sup>34</sup> CME Globex is a global electronic trading platform for trading futures products. NYMEX ClearPort Clearing provides traders an interface where transactions are posted, margin requirements are calculated, and the transactions are processed by the clearinghouse.

<sup>35</sup> David Stellfox, “Industry Moves Closer to Having Standardized Uranium Contract,” *NuclearFuel*, February 9, 2009.

<sup>36</sup> World Nuclear Association, *World Uranium Mining*, <http://www.world-nuclear.org/info/inf23.html>.

<sup>37</sup> World Nuclear Association, *Uranium Markets*, March 2007, at <http://www.world-nuclear.org/info/inf22.html>

<sup>38</sup> *Ibid.*



provide confidence that uranium resources will remain adequate to meet projected demands even were requirements to significantly increase,” according to NEA.<sup>39</sup>

## Conversion

In the conversion process, the yellowcake is purified, chemically reacted with hydrofluoric acid to form uranium hexafluoride (UF<sub>6</sub>) gas, and then transferred into cylinders, where it cools and condenses to a solid. Uranium hexafluoride contains two isotopes of uranium—heavier <sup>238</sup>U and lighter fissionable <sup>235</sup>U, which makes up ~0.7% of uranium by weight. The annual U.S. demand for yellowcake conversion is approximately 22,000 metric tons uranium (MTU). After conversion, the uranium hexafluoride is ready for enrichment.

Five commercial conversion companies operate worldwide—in the United States, Canada, France, the United Kingdom, and Russia (**Table 2**). ConverDyn in Metropolis, IL, the only conversion plant operating in the United States, produces 14,000 MTU annually.

**Table 2. Commercial UF<sub>6</sub> Conversion Facilities**  
(metric tons uranium/year)

Country	Company	Facility	Capacity
Canada	Cameco	Port Hope	12,500
China	CNCC	Lanzhou	1,500
France	Comurhex	Peirrelatte 1 Peirrelatte 2	14,000 350
Russian Federation	Minatom	Angarsk Tomsk	20,000 10,000
U.K.	BNFL	Springfields Line 4	6,000
U.S.	Converdyn	Metropolis	14,000

Source: IAEA Country Nuclear Fuel Cycle Profiles, 2<sup>nd</sup> ed.

## Enrichment

For use as fuel in light water reactors, uranium must be enriched in the isotope <sup>235</sup>U above its natural concentration of 0.7%. By heating UF<sub>6</sub> to turn it into a gas, the enrichment process can take advantage of the slight difference in atomic mass between <sup>235</sup>U and <sup>238</sup>U. The typical enrichment process requires about 10 lbs of uranium U<sub>3</sub>O<sub>8</sub> to produce 1 lb of low-enriched uranium hexafluoride (UF<sub>6</sub>) product, with a <sup>235</sup>U concentration of 3-5%.

About 90% of the world’s reactors (all except heavy water reactors) require enriched uranium fuel. More than 90% of those uranium enrichment requirements are supplied by facilities in the United States (including diluted weapons material), Russia, France, Great Britain, Germany, and the Netherlands. The remainder comes from Japan, China, and Brazil. Thirty-one countries currently operate commercial nuclear power plants. Most countries, therefore, rely on enrichment services outside their borders. An enrichment plant to serve a country with only a few reactors

<sup>39</sup> Nuclear Energy Agency, *op. cit.*, p. 13.

would appear economically nonviable, given that a single large enrichment plant can supply up to 25% of the world market (currently estimated at 45 million separative work units, or SWUs).<sup>40</sup>

Commercial uranium enrichment employs either gaseous diffusion or high speed centrifuges. In gaseous diffusion, a thin semiporous barrier holds back more of the heavier  $^{238}\text{U}$  than the lighter  $^{235}\text{U}$ . A series of cascading diffusers successively increases the  $^{235}\text{U}$  concentration. Centrifuge enrichment spins the uranium hexafluoride gas at ultra-high speeds to separate the lighter  $^{235}\text{U}$ . A series of cascading centrifuges successively enriches the gas in  $^{235}\text{U}$ . Final enrichment will vary depending on the requirements of a specific reactor, normally up to about 5%.

Gaseous diffusion technology was first developed in the United States and later adopted by France and Britain. It is more energy-intensive than the newer centrifuge enrichment process. However, the legacy gaseous diffusion plants currently operating in the United States and France have higher capacities than the newer centrifuge enrichment plants.

Uranium enrichment services are sold in kilograms (kg) or metric tons (1,000 kg) separative work units (SWU), which is a measure of the amount of work needed (in the thermodynamic sense) to enhance the  $^{235}\text{U}$  concentration. The number of SWUs required to produce fuel depends on several factors: the quantity of fuel required, level of enrichment required, the initial enrichment of the feed (0.711% in the case of natural uranium), and the “tails assay,” which is the  $^{235}\text{U}$  concentration remaining in the depleted processing stream. For example, to produce 1 kg of uranium enriched to 3%  $^{235}\text{U}$ , at a tails assay of 0.2%  $^{235}\text{U}$ , 4.3 kg-SWU are used to process 5.5 kg of natural uranium.<sup>41</sup> The price of yellowcake is an important factor in enrichment demand. Under high price conditions, it may be economically preferable to expend more SWUs enriching a lesser quantity of yellowcake, thus leaving a lower tails assay.

Nuclear plant operators can buy uranium yellowcake and have it converted and enriched, or buy low-enriched uranium (LEU). Commercial enrichment services are offered by a number of international sources (**Table 3**), with worldwide annual capacity of 47,855 metric tons SWU. In 2008, U.S. nuclear plant operators contracted five companies worldwide to provide 12.6 million kilogram SWU (12,600 metric tons SWU, of which 15% was provided in the United States).<sup>42</sup>

**Table 3. Operating Commercial Uranium Enrichment Facilities**  
(metric tons SWU/year)

Facility Name	Country	Process	Capacity
Paducah Gaseous Diffusion	United States	Gaseous Diffusion	11,300
Eurodif (Georges Besse)	France	Gaseous Diffusion	10,800
Ekaterinburg (Sverdlovsk-44)	Russian Federation	Centrifuge	7,000
Siberian Chemical Combine (Seversk)	Russian Federation	Centrifuge (downblended)	4,000
Urenco Capenhurst	United Kingdom	Centrifuge	4,000

<sup>40</sup> Ruthane Neely and Jeff Combs, “Diffusion Fades Away,” *Nuclear Engineering International*, September 2006, p. 24.

<sup>41</sup> Thomas L. Neff, *The International Uranium Market*, Ballinger Publishing Co., 1984.

<sup>42</sup> EIA, Purchases of Enrichment Services by Owners and Operators of U.S. Civilian Nuclear Power Reactors by Origin Country and Year, <http://www.eia.doe.gov/cneaf/nuclear/umar/table16.html>.

Facility Name	Country	Process	Capacity
Krasnoyarsk	Russian Federation	Centrifuge	3,000
Urenco Nederland	Netherlands	Centrifuge	2,900
Urenco Deutschland	Germany	Centrifuge	1,800
Rokkasho Uranium Enrichment Plant	Japan	Centrifuge	1,050
Angarsk	Russian Federation	Centrifuge	1,000
Lanzhou 2	China	Centrifuge	500
Shaanxi Uranium Enrichment Plant	China	Centrifuge	500
Kahuta	Pakistan	Centrifuge	5
<b>Total</b>			<b>47,855</b>

**Source:** International Atomic Energy Agency, Nuclear Fuel Cycle Information System.

The U.S. DOE had operated gaseous diffusion enrichment plants in Oak Ridge, TN, Paducah, KY, and Portsmouth, OH, to produce high-enriched uranium used in the nuclear weapons program. The plants later produced low-enriched uranium for commercial nuclear power around the world, although production at the Oak Ridge K-25 enrichment site ceased in 1985. The Energy Policy Act of 1992 established the United States Enrichment Corporation (USEC) as a government-owned corporation to take over DOE's uranium enrichment services business. The corporation was privatized as USEC Inc. in 1998. In 2001, USEC ceased uranium enrichment operations in Portsmouth and consolidated operations in Paducah. The Paducah gaseous diffusion plant is the only operating enrichment facility in the United States. In 2004, USEC announced plans to build the American Centrifuge Plant on the site of the Portsmouth, OH, gaseous diffusion plant. The new gas centrifuge enrichment plant is to have 11,500 centrifuges with an annual capacity of 3.8 million SWU.<sup>43</sup> Construction of the plant was suspended in August 2009, with restart dependent on DOE approval of a loan guarantee.<sup>44</sup> USEC currently supplies approximately 51% of the U.S. demand for enrichment services, mostly with blended-down Russian HEU, as discussed below.

Urenco, a joint Dutch, German, and British enrichment consortium, was set up in the 1970s following the signing of the Treaty of Almelo. Urenco operates enrichment plants in Germany, the Netherlands, and the United Kingdom to supply customers in Europe, North America, and East Asia. Its U.S. affiliate, Louisiana Energy Services, has begun constructing the gas centrifuge National Enrichment Facility (NEF) in New Mexico.<sup>45</sup> NEF is expected to produce 3 million SWUs annually when it reaches full operational capacity in 2013—meeting approximately 25% of the current U.S. demand.<sup>46</sup> In 2006, Urenco estimated that it provided around 23% of the world market share in enrichment services.

Areva operates the Eurodif gaseous diffusion production plant (located on the Tricastin nuclear site in France) to enrich uranium for some 100 nuclear reactors in France and throughout the

<sup>43</sup> *USEC to Site American Centrifuge Plant in Piketon, Ohio—Technology Expected to Be World's Most Efficient for Enriching Nuclear Fuel*, at [http://www.usec.com/v2001\\_02/Content/News/NewsTemplate.asp?page=v2001\\_02/Content/News/NewsFiles/01-12-04.htm](http://www.usec.com/v2001_02/Content/News/NewsTemplate.asp?page=v2001_02/Content/News/NewsFiles/01-12-04.htm).

<sup>44</sup> USEC Inc., "USEC Provides American Centrifuge Update," press release, November 2, 2009, <http://www.usec.com/NewsRoom/NewsReleases/USECInc/2009/2009-11-02-USEC-Provides-American-Centrifuge.htm>.

<sup>45</sup> URENCO <http://www.urenco.com/fullArticle.aspx?m=1371>.

<sup>46</sup> URENCO <http://www.urenco.com/fullArticle.aspx?m=1371>.

world.<sup>47</sup> Areva provides toll conversion services and uranium yellowcake through its subsidiary Comurhex. Areva applied to NRC at the end of 2008 for a license to build and operate a gas centrifuge enrichment plant in Idaho.<sup>48</sup>

Under the 1993 U.S.-Russian Federation Megatons to Megawatts program, highly enriched uranium from dismantled Russian nuclear warheads is converted into low-enriched uranium fuel for use in commercial U.S. nuclear power plants.<sup>49</sup> The HEU Agreement, as it is known, provides for the purchase over 20 years of 500 metric tons highly enriched uranium downblended to commercial grade low-enriched uranium (delivered as UF<sub>6</sub>). The agreement provides about 46% of the current U.S. demand for enrichment.

The world uranium enrichment industry is currently undergoing a technological transformation from gaseous diffusion to centrifuges, primarily because centrifuges need only a fraction of the energy required by gaseous diffusion. In 1996, 57% of the world's commercial enrichment came from gaseous diffusion plants, a level that dropped to 35% in 2006. As noted above, the United States' only currently operating enrichment facility, in Paducah, KY, is planned to be replaced with a centrifuge plant in Portsmouth, OH. The world's only other operating gaseous diffusion plant, at Areva's Tricastin site in France, is to be replaced by a centrifuge plant by around 2012.<sup>50</sup>

## **Fuel Fabrication**

Like enrichment, fuel fabrication is a specialized service rather than a commodity transaction. The now low-enriched uranium (UF<sub>6</sub>) undergoes one final process, converting to uranium dioxide (UO<sub>2</sub>), before the final stage of fuel fabrication. It is then sintered into pellets and loaded into zirconium alloy tubes (fuel rods) about 12-15 feet long and half an inch in diameter. The fuel rods are bundled into fuel assemblies, which vary from fewer than 100 to as many as 300 rods apiece.

Fuel fabrication services are offered by 16 suppliers operating in 18 countries at around 34 facilities. In 2002, IAEA estimated that worldwide fabrication capacity of 19,000 tons (fuel assemblies and elements) exceeded the demand by 53%.<sup>51</sup> The oversupply had existed for many years, and, as a consequence, facilities were shut down and ownership was consolidated.

Essentially all U.S. fabrication demand is met by three companies providing fabrication service at four facilities: Framatome ANP Inc. in Lynchburg, VA, and Richland, WA; Global Nuclear Fuel in Wilmington, NC; and Westinghouse Electric in Columbia, SC. About 30 other nuclear fuel fabrication facilities are in operation elsewhere in the world.<sup>52</sup>

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<sup>47</sup> AREVA [http://www.areva-nc.com/servlet/ContentServer?pagename=cogema\\_en%2FPage%2Fpage\\_site\\_prod\\_full\\_template&c=Page&cid=1039482707079](http://www.areva-nc.com/servlet/ContentServer?pagename=cogema_en%2FPage%2Fpage_site_prod_full_template&c=Page&cid=1039482707079).

<sup>48</sup> NRC, *Uranium Enrichment*, <http://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html>.

<sup>49</sup> <http://www.usec.com>.

<sup>50</sup> Ibid.

<sup>51</sup> IAEA, *Country Nuclear Fuel Cycle Profiles*, 2<sup>nd</sup> ed.

<sup>52</sup> Nuclear Engineering International, *2007 World Nuclear Industry Handbook*, p. 207.

## Final Stages of the Fuel Cycle

The final stages of the nuclear fuel cycle take place after nuclear fuel assemblies have been loaded into a reactor. In the reactor, the uranium 235 ( $^{235}\text{U}$ ) splits, or fissions, releasing energy, neutrons, and fission products (highly radioactive fragments of  $^{235}\text{U}$  nuclei). The neutrons may cause other  $^{235}\text{U}$  nuclei to fission, creating a nuclear chain reaction. Some neutrons are also absorbed by  $^{238}\text{U}$  nuclei to create plutonium 239 ( $^{239}\text{Pu}$ ), which itself may then fission.

After several years in the reactor, fuel assemblies will build up too many neutron-absorbing fission products and become too depleted in fissile  $^{235}\text{U}$  to efficiently sustain a nuclear chain reaction. At that point, the assemblies are considered spent nuclear fuel and removed from the reactor. Spent fuel typically contains about 1%  $^{235}\text{U}$ , 1% plutonium, 4% fission products and other radioactive waste, and the remainder  $^{238}\text{U}$ .

The last stage of the fuel cycle, after spent fuel is removed from a reactor, has proved highly contentious. One option is to directly dispose of spent fuel in a deep geologic repository to isolate it for the hundreds of thousands of years that it may remain hazardous. The other option is to reprocess the spent fuel to separate the uranium and plutonium for use in new fuel. Supporters of reprocessing, or recycling, contend that it could greatly reduce the volume and longevity of nuclear waste while vastly expanding the amount of energy extracted from the world's uranium resources. Opponents contend that commercial use of separated plutonium—a key material in nuclear weapons as well as reactor fuel—poses a nuclear weapons proliferation threat.

Commercial-scale spent fuel reprocessing is currently conducted in France, Britain, and Russia. The  $^{239}\text{Pu}$  they produce is blended with uranium to make mixed-oxide (MOX) fuel, in which the  $^{239}\text{Pu}$  largely substitutes for  $^{235}\text{U}$ . Two French reprocessing plants at La Hague can each reprocess up to 800 metric tons of spent fuel per year, while Britain's THORP facility at Sellafield has a capacity of 900 metric tons per year. Russia has a 400-ton plant at Ozersk, and Japan is building an 800-ton plant at Rokkasho to succeed a 90-ton demonstration facility at Tokai Mura. Britain and France also have older plants to reprocess gas-cooled reactor fuel, and India has a 275-ton plant.<sup>53</sup> About 200 metric tons of MOX fuel is used annually, about 2% of new nuclear fuel,<sup>54</sup> equivalent to about 2,000 metric tons of mined uranium.<sup>55</sup>

However, the benefits of reprocessing spent fuel to make MOX fuel for today's nuclear power plants are modest. Existing commercial light water reactors use ordinary water to slow down, or "moderate," the neutrons released by the fission process. The relatively slow (thermal) neutrons are highly efficient in causing fission in certain isotopes of heavy elements, such as  $^{235}\text{U}$  and  $^{239}\text{Pu}$ .<sup>56</sup> Therefore, lower quantities of those isotopes are needed in nuclear fuel to sustain a nuclear chain reaction. The downside is that thermal neutrons cannot efficiently induce fission in more than a few specific isotopes. In today's commercial reactors, therefore, the buildup of non-fissile plutonium and other isotopes sharply limits the number of reprocessing cycles before the recycled fuel can no longer sustain a nuclear chain reaction and must be stored or disposed of.

<sup>53</sup> World Nuclear Association, *Processing of Used Nuclear Fuel for Recycle*, March 2007, at <http://www.world-nuclear.org/info/inf69.html>.

<sup>54</sup> World Nuclear Association, *Mixed Oxide Fuel (MOX)*, November 2006, at <http://www.world-nuclear.org/info/inf29.html>.

<sup>55</sup> World Nuclear Association, *Uranium Markets*, March 2007.

<sup>56</sup> Isotopes are atoms of the same chemical element but with different numbers of neutrons in their nuclei.

In contrast, “fast” neutrons, which have not been moderated, are less effective in inducing fission than thermal neutrons but can induce fission in all actinides, including all plutonium isotopes. Therefore, nuclear fuel for a fast reactor must have a higher proportion of fissionable isotopes than a thermal reactor to sustain a chain reaction, but a larger number of different isotopes can constitute that fissionable proportion.

A fast reactor’s ability to fission all actinides (actinium and heavier elements), makes it theoretically possible to repeatedly separate those materials from spent fuel and feed them back into the reactor until they are entirely fissioned. Fast reactors are also ideal for “breeding” the maximum amount of  $^{239}\text{Pu}$  from  $^{238}\text{U}$ , eventually converting virtually all of natural uranium to useable nuclear fuel.<sup>57</sup> Current reprocessing programs are generally viewed by their proponents as interim steps toward a commercial nuclear fuel cycle based on fast reactors.

## Waste Disposal and Energy Security

Reprocessing of spent fuel from fast breeder reactors has long been the ultimate goal of nuclear power supporters. As noted above, fast reactors (operated either as breeders or non-breeders) can largely eliminate plutonium from nuclear waste and greatly extend uranium supplies. But opponents contend that such potential benefits are not worth the costs and nonproliferation risks.

Removing uranium from spent nuclear fuel through reprocessing would eliminate most of the volume of radioactive material requiring disposal in a deep geologic repository. In addition, the removal of plutonium and conversion to shorter-lived fission products would eliminate most of the long-term (post-1,000 years) radioactivity in nuclear waste. But the waste resulting from reprocessing would have nearly the same short-term radioactivity and heat as the original spent fuel, because the reprocessing waste consists primarily of fission products, which generate most of the radioactivity and heat in spent fuel. Because heat is the main limiting factor on repository capacity, conventional reprocessing would not provide major disposal benefits in the near term.

To address that problem, various proposals have been made to further separate the primary heat-generating fission products—cesium 137 and strontium 90—from high-level waste for separate storage and decay over several hundred years. Such a process could greatly increase repository capacity, although it would require an alternative secure storage system for the cesium and strontium for hundreds of years.

Energy security has been a primary driving force behind the development of nuclear energy, particularly in countries such as France and Japan that have few natural energy resources. Recent cutoffs in oil and gas around the world have underscored the instability of oil and gas supply, which could be mitigated by nuclear energy. For example, in 2006, a natural gas price dispute between Russia and Ukraine resulted in a temporary cutoff of natural gas to Western and Central Europe; in 2007, price disputes between Russia and Azerbaijan and Belarus caused a temporary cutoff in oil to Russia from Azerbaijan and in oil from Russia to Germany, Poland, and Slovakia.

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<sup>57</sup> The core of a breeder reactor is configured so that more fissile  $^{239}\text{Pu}$  is produced from  $^{238}\text{U}$  than the amount of fissile material initially loaded into the core that is consumed ( $^{235}\text{U}$  or  $^{239}\text{Pu}$ ). In a breeder, therefore, enough fissile material could be recovered through reprocessing to refuel the reactor and to provide fuel for additional breeders. The core of a fast reactor can also be configured to produce less  $^{239}\text{Pu}$  than fissile material consumed, if the primary goal is to eliminate  $^{239}\text{Pu}$  from spent fuel. In that case, much less  $^{238}\text{U}$  ultimately would be converted to  $^{239}\text{Pu}$  and therefore less total energy produced from a given amount of natural uranium.

Moreover, temporary production shutdowns in the Gulf of Mexico and the Trans-Alaskan pipeline, instability in Nigeria, and nationalization of oil and gas fields in Bolivia in 2006 have all raised concerns about oil and gas supplies and worldwide price volatility. Relative to gas and oil, the ability to stockpile uranium is widely seen as offering greater assurances of weathering potential cutoffs.

Worldwide uranium resources are generally considered to be sufficient for at least several decades. Uranium supply is highly diversified, with uranium mining spread across the globe, while uranium conversion, enrichment, and fuel fabrication are more concentrated in a handful of countries. But because most reactors around the world rely at least partly on foreign sources of uranium and nuclear fuel services, nuclear reactors nearly everywhere face some level of supply vulnerability. To mitigate such concern, countries such as China, India, and Japan are seeking to secure long-term uranium contracts to support nuclear expansion goals. Efforts are underway to establish an international nuclear fuel bank to provide greater certainty in fuel supplies, as discussed in the next section.

Ultimately, only the development of breeder reactors and reprocessing could provide complete nuclear energy independence. This remains the long-term goal of resource-poor France and Japan, and Russia as well, although their research and development programs have faced numerous obstacles and schedule slowdowns.

## **Proposals on the Fuel Cycle<sup>58</sup>**

Proposals addressing access to the full nuclear fuel cycle have ranged from seeking a formal commitment to forswear enrichment and reprocessing technology, to a de facto approach in which a state does not operate fuel cycle facilities but makes no explicit commitment to give them up, to no restrictions at all. Current proposals generally aim to persuade countries not to develop their own fuel production capabilities by providing economically attractive alternatives that allay concerns about politically motivated interruption to fuel supply. Most proposals focus on this front-end problem, dealing with fuel supply and production issues. Ultimately, these proposals are aimed at preventing an increase in the number of states that would be capable of producing weapons-usable nuclear material.

The main proposals under discussion are outlined here in categories—those addressing the full fuel cycle, those addressing the “front-end” or assurance of fuel supply issues (including fuel banks and multilateral enrichment services), and those focusing on the “back-end” or waste disposal solutions.

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<sup>58</sup> This section was prepared by Mary Beth Nikitin (Analyst in WMD Nonproliferation) in the Foreign Affairs, Defense, and Trade Division, and Anthony Andrews (Specialist in Energy Policy) in the Resources, Science, and Industry Division.

## Comprehensive Proposals

### El Baradei Proposal

IAEA Director General Mohamed El Baradei in 2003 proposed a three-pronged approach to limiting the processing of weapon-usable material (separated plutonium and high-enriched uranium) in civilian nuclear fuel cycles.<sup>59</sup> First, he would place all enrichment and reprocessing facilities under multinational control. Second, he would develop new nuclear technologies that would not produce weapons-usable fissile material—in other words, “the holy grail” of a proliferation-resistant fuel cycle. In his October 2003 article in the *Economist* where he laid out these ideas, El Baradei maintained, “This is not a futuristic dream; much of the technology for proliferation-resistant nuclear-energy systems has already been developed or is actively being researched.” Third, El Baradei proposed considering “multinational approaches to the management and disposal of spent fuel and radioactive waste.” El Baradei did not place any nonproliferation requirements on participation, but instead suggested that the system “should be inclusive; nuclear-weapon states, non-nuclear-weapon states, and those outside the current non-proliferation regime should all have a seat at the table.” Further, he noted that a future system should achieve full parity among all states under a new security structure that does not depend on nuclear weapons or nuclear deterrence.

### *IAEA Experts Group/INFCIRC/640*

In February 2005, an Expert Group commissioned by IAEA Director General El Baradei presented a report, “Multilateral Approaches to the Nuclear Fuel Cycle.”<sup>60</sup> The Expert Group studied several possible approaches to securing the operation of proliferation-sensitive nuclear fuel cycle activities (uranium enrichment, reprocessing and spent fuel disposal, and storage of spent fuel) and analyzed the incentives and disincentives for states to participate. The report reviewed relevant past and present experience. The Group’s suggested approaches included the following:

- Reinforce existing market mechanisms by providing additional supply guarantees by suppliers and/or the IAEA (fuel bank).
- Convert existing facilities to multinational facilities.
- Create co-managed, jointly owned facilities.

The Group concluded that “in reality, countries will enter into multilateral arrangements according to the economic and political incentives and disincentives offered by these arrangements.”<sup>61</sup> The report noted that no legal framework existed for requiring states to join supply assurance arrangements.

In September 2006, the IAEA sponsored a conference entitled “New Framework for the Utilization of Nuclear Energy in the 21<sup>st</sup> Century: Assurances of Supply and Non-Proliferation,”

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<sup>59</sup> “Towards a Safer World,” at <http://f40.iaea.org/worldatom/Press/Statements/2003/ebTE20031016.shtml>.

<sup>60</sup> “Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency,” February 22, 2005, (INFCIRC/640). Available at <http://www.iaea.org/Publications/ocuments/Infcircs/2005/infcirc640.pdf>.

<sup>61</sup> *Ibid.*, p. 98.



which addressed proposals to provide fuel assurances. The IAEA presented a report on fuel assurance options at the June 2007 Board of Governors meeting analyzing the various proposals put forth to date.<sup>62</sup> A potential framework for nuclear supply assurances could have three stages: (1) existing market arrangements; (2) back-up commitments by suppliers in case of a politically motivated interruption of supply if nonproliferation criteria are met; (3) a physical LEU material reserve.<sup>63</sup> The report emphasizes that participation in these arrangements should be voluntary, that progress on this question will be incremental and that many options should be explored to give consumer states sufficient choices to meet their needs. The report is still under discussion by IAEA Board members.

### **President Bush's 2004 Proposal**

In a speech at the National Defense University on February 11, 2004, President Bush said the world needed to “close a loophole” in the NPT that allows states to legally acquire the technology to produce nuclear material which could be used for a clandestine weapons program. To remedy this, he proposed that the 40 members of the Nuclear Suppliers Group (NSG) should “refuse to sell enrichment and reprocessing equipment and technologies to any state that does not already possess full-scale, functioning enrichment and reprocessing plants.”<sup>64</sup> President Bush also called on the world's leading nuclear fuel services exporters to “ensure that states have reliable access at reasonable cost to fuel for civilian reactors, so long as those states renounce enrichment and reprocessing.”

President Bush's 2004 proposal was the only one that calls for countries to explicitly “renounce” pursuit of enrichment or reprocessing technologies in exchange for reliable access to nuclear fuel, and proved controversial. Many non-nuclear-weapon states saw this as an attempt to limit their inalienable right to the use of peaceful nuclear energy under Article IV of the NPT and are not willing to consider limits on peaceful nuclear technologies until more progress on nuclear disarmament has been made.

Fundamental questions about this original formulation were raised. For example, who is included in the group of supplier states and how is “full-scale, functioning plants” defined? Would Iran's enrichment program qualify today, even if it did not back in 2004? And what about non-NPT states with the full fuel cycle as part of their weapons programs? Also, how would related technologies be treated? For example, would restrictions also apply to post-irradiation experiments on spent nuclear fuel, which yield significant data about reactor operations, but can also contribute to knowledge about reprocessing for weapons purposes? Since 2004, delay in defining these terms appears to have provided an incentive for some states, such as Canada, South Africa, Argentina, and Australia, to expedite their pursuit of a full operational enrichment capability so as not to be excluded when and if such a division between fuel cycle haves and have-nots is made.

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<sup>62</sup> International Atomic Energy Agency, *Possible New Framework for the Utilization of Nuclear Energy: Options for Assurance of Supply of Nuclear Fuel*, June 2007.

<sup>63</sup> Tariq Rauf, “Realizing Nuclear Fuel Assurances: Third Time's the Charm,” Presentation to the Carnegie International Nonproliferation Conference, June 24, 2007, at [http://www.carnegieendowment.org/files/fuel\\_assurances\\_rauf.pdf](http://www.carnegieendowment.org/files/fuel_assurances_rauf.pdf).

<sup>64</sup> “President Announces New Measures to Counter the Threat of WMD,” February 11, 2004, at <http://www.whitehouse.gov/news/releases/2004/02/20040211-4.html>.

## **Russia's "Global Nuclear Power Infrastructure"**

In January 2006, Russian President Vladimir Putin proposed the Global Nuclear Power Infrastructure initiative that would include four kinds of cooperation: creation of international uranium-enrichment centers (IUECs), international centers for reprocessing and storing spent nuclear fuel, international centers for training and certifying nuclear power plant staff, and an international research effort on proliferation-resistant nuclear energy technology. The international fuel cycle centers would be under joint ownership and co-management. They would be commercial joint ventures (that is, no state financing), with advisory boards consisting of government, industry, and IAEA professionals. The IAEA would not have a vote on these boards, but would play an advisory role, while also certifying the fuel provision commitments.

Recipient countries under Putin's proposal would receive fuel cycle services, but access to sensitive technology would stay in the hands of the supplier state. Russia has offered a similar arrangement to Iran—to jointly enrich uranium on Russian territory. Iran has not yet accepted this offer, but it is still part of ongoing negotiations with Iran over its nuclear program. Russia has also made the return of spent fuel from the Bushehr nuclear plant it is constructing in Iran a condition of supply, so that no plutonium can be extracted from the spent fuel.<sup>65</sup> To date, progress has been made in establishing the IUEC and in establishing an LEU reserve at Angarsk (see below). Russia has also announced creation of a center of excellence for nuclear personnel at Obninsk, and actively participates in joint research efforts on fast reactors such as the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO).

## **Assurance of Fuel Supply: Supplier Guarantees**

The following proposals focus on back-up fuel supply assurances designed to complement, but not impact or supplant, the commercial uranium market.

### **Six Country Concept**

In May 2006, six governments—France, Germany, the Netherlands, Russia, the United Kingdom, and the United States—proposed a "Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel"<sup>66</sup> (referred to here as the Six Country Concept). This proposal reportedly developed from a U.S. initiative following President Bush's 2004 proposal. It would not require states to forgo enrichment and reprocessing, but participation would be limited to those states that did not currently have enrichment and reprocessing capabilities.

The Six Country Concept calls for a multi-tiered backup mechanism to ensure the supply of low enriched uranium (LEU) for nuclear fuel. The proposal would work as follows: (1) A commercial supply relationship is interrupted for reasons other than nonproliferation; (2) The recipient or supplier state can approach the IAEA to request backup supply; (3) The IAEA would rule out commercial or technical reasons for interruption (to avoid a market disruption) and assess

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<sup>65</sup> "The Last Word: Sergei Kirienko," *Newsweek*, February 20, 2006 issue, at <http://www.msnbc.msn.com/id/11299203/site/newsweek/>.

<sup>66</sup> "Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel," Proposal as sent to the IAEA from France, Germany, the Netherlands, Russia, Ireland, and the United States, May 31, 2006, IAEA GOV/INF/2006/10. Available at [http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2006/cn147\\_ConceptRA\\_NF.pdf](http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2006/cn147_ConceptRA_NF.pdf).

whether the recipient meets the following qualifications: it must have a comprehensive safeguards agreement and Additional Protocol in force; it must adhere to international nuclear safety and physical protection standards; and it is not pursuing sensitive fuel cycle activities (which are not defined); (4) The IAEA would facilitate new arrangements with alternative suppliers.

Two mechanisms were proposed to create multiple tiers of assurances: including a standard backup provision in commercial contracts, and establishing reserves of LEU (not necessarily held by the IAEA, but possibly with rights regarding the use of the reserves). The Six Country Concept addressed several future options, all of which are longer-term in nature. They include providing reliable access to existing reprocessing capabilities for spent fuel management; multilateral cooperation in fresh fuel fabrication and spent fuel management; international enrichment centers; and new fuel cycle technology development that could incorporate fuel supply assurances.

### **World Nuclear Association**

In May 2006, the private-sector World Nuclear Association (WNA) Working Group on Security of the International Nuclear Fuel Cycle outlined proposals for assuring front-end and back-end nuclear fuel supplies.<sup>67</sup> Like the Six Country Concept, the WNA proposal envisions a system of supply assurances that starts first with normal market procedures attempting to reestablish nuclear fuel supply after interruptions. Also similar to the Six Country proposal, a pre-established network of suppliers could be triggered through the IAEA if supply were interrupted for political reasons. If that network then failed, stocks held by national governments could be used.

The first tier of assurances, therefore, is through commercial suppliers. The second level of supply commitment would use a “standard backup supply clause” in enrichment contracts, supported by governments and the IAEA. “To ensure that no single enricher is unfairly burdened with the responsibility of providing backup supply, the other (remaining) enrichers would then supply the contracted enrichment in equal shares under terms agreed between the IAEA and the enrichers,” according to the proposal.

For fuel fabrication, a backup supply system would be more complicated, according to the WNA report. “Because fuel design is specific to each reactor design, an effective mechanism would require stockpiling of different fuel types/designs. The cost of such a mechanism could thus be substantial,” according to the report. However, WNA noted that unlike uranium enrichment technology, uranium fuel fabrication is not of proliferation concern.

The WNA report also noted the need for back-end nuclear fuel cycle supply assurances, to prevent a future scenario in which reprocessing technologies spread as nuclear power programs expand. The report recommends that a clear option to reprocess spent fuel at affordable prices be offered to states that do not have indigenous reprocessing programs. Such assurances would be part of a longer-term approach.

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<sup>67</sup> WNA’s report is available at <http://www.world-nuclear.org/reference/pdf/security.pdf>.

## **Japan's IAEA Standby Arrangements System**

Japan presented a “complementary proposal” to the Six Country Concept at the IAEA in September 2006. Japan's concerns with the Six Country Concept centered on the implication that it would deny the right for states to use nuclear technology for commercial purposes and because it assured the supply only of LEU, rather than all front-end nuclear fuel cycle services. Japan proposed instead to create an “IAEA Standby Arrangements System” that would act as an early warning system to prevent a break in supply to recipients. With a list of supply capacities from each state updated annually and a virtual bank of front-end fuel cycle services (from natural uranium to fuel fabrication), the IAEA would facilitate supply to recipient states before supply was completely stopped. States determined by the IAEA Board of Governors to be in good non-proliferation standing by the IAEA could participate.

## **UK “Nuclear Fuel Assurance (NFA)”**

The United Kingdom has proposed a political assurance of non-interference in the delivery of commercial nuclear contracts, called a nuclear fuel assurance (NFA). This concept incorporates an earlier proposal that would create “enrichment bonds” to give advance assurance of export approvals for nuclear fuel to recipient states. As the UK Prime Minister's report, *Road to 2010*, summarized the NFA: “The UK's Nuclear Fuel Assurance is complementary to other proposals put forward and provides a guarantee that export licences for nuclear fuel enrichment services would only be withheld in the event of non-compliance with non-proliferation obligations.”<sup>68</sup>

The NFA would be a government-to-government agreement between supplier state or states and the recipient state, with the IAEA as co-signatory. The supplier government would guarantee that, subject to the IAEA's determination that the recipient was in good nonproliferation standing, national enrichment providers will be given the necessary export approvals to supply the recipient states. It is a transparent legal mechanism designed to give further credible assurance of supply with a “prior consent to export” arrangement. The IAEA would make the final decision on whether conditions had been met to allow the export of LEU.<sup>69</sup> A model agreement to be used as a standard for an NFA could be adopted by the Board of Governors. The NFA concept has been presented to the IAEA Board of Governors and is still under discussion.

## **Assurance of Fuel Supply: Fuel Reserves**

A fuel reserve is meant to appeal to countries concerned about a possible cut-off in their nuclear fuel supply for reasons unrelated to nonproliferation, such as a non-commercial or political dispute with the supplier country. A fuel bank under IAEA control has achieved initial funding pledges but is still under consideration by the IAEA Board of Governors. The IAEA Board approved terms for a Russian-operated “fuel reserve” in November 2009. Additionally, the United States has declared that it would downblend excess military HEU to LEU and hold it in reserve as part of the Six-Country Concept, under the Department of Energy's Reliable Fuel Supply program. These three proposals are discussed below.

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<sup>68</sup> *The Road to 2010: addressing the nuclear question in the 21<sup>st</sup> century*, July 2009, <http://www.cabinetoffice.gov.uk/reports/roadto2010.aspx>

<sup>69</sup> INFCIRC/707, June 4, 2007.

## **IAEA LEU Fuel Bank**

In September 2006, former Senator Sam Nunn, co-chairman of the Nuclear Threat Initiative (NTI),<sup>70</sup> announced NTI's pledge of \$50 million as seed money to create a low-enriched uranium stockpile owned and managed by the IAEA. NTI believes that the establishment of such an LEU reserve would assure an international supply of nuclear fuel on a non-discriminatory, non-political basis to recipient states.

Provision of the NTI money was contingent on the IAEA taking the necessary preparatory actions to establish the reserve and on contribution of an additional \$100 million or an equivalent value of LEU by one or more IAEA Member States.<sup>71</sup> The latter condition was met in March 2009. The U.S. Congress approved \$50 million for an international fuel bank in December 2007 (see below). Norway pledged \$5 million to the fuel bank in February 2008.<sup>72</sup> The United Arab Emirates announced a contribution of \$10 million on August 1, 2008.<sup>73</sup> The European Union pledged 25 million euros in December 2008,<sup>74</sup> and Kuwait pledged \$10 million in March 2009.<sup>75</sup> To date, the IAEA has received the U.S. government contribution, which is being held in a suspense account until the Board of Governors approves the LEU bank.

No policy conditions have been set by donor countries—policy questions are meant to be solved by the IAEA and member states. Key issues still to be determined include the reserve's content, location, criteria for determining access to the stocks including safety and export control standards, the fuel's pricing, and how the fuel in reserve would be fabricated into the appropriate fuel type for the customer's reactor.<sup>76</sup> Kazakhstan proposed in May 2009 that it host the fuel bank.

The IAEA secretariat drew up draft plans for the fuel bank, which were presented to the Board of Governors at its June 2009 meeting along with a proposal for a Russian-hosted bank and the German-proposed multilateral enrichment project (see below). However, developing countries reportedly rejected the director general's proposal to negotiate details and approve these arrangements at the September Board meeting. Opponents and skeptics cite concerns that their legal rights under the NPT to develop fuel cycle facilities would be infringed upon if such

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<sup>70</sup> Nuclear Threat Initiative is a private organization founded in 2001 by Mr. Ted Turner and former Senator Sam Nunn. It is now classified as a 501(c)3 public charity.

<sup>71</sup> Nuclear Threat Initiative Commits \$50 million to Create IAEA Nuclear Fuel Bank, International Atomic Energy Agency Press Release, September 19, 2006. Available at [http://www.nti.org/c\\_press/release\\_IAEA\\_Fuelbank\\_091906.pdf](http://www.nti.org/c_press/release_IAEA_Fuelbank_091906.pdf).

<sup>72</sup> "Norway Contributes \$5 Million to IAEA Nuclear Fuel Reserve," Norwegian Ministry of Foreign Affairs Press Release No. 027/08, February 27, 2008. <http://www.regjeringen.no/en/dep/ud/Press-Contacts/News/2008/fuelreserve.html?id=50210>

<sup>73</sup> "UAE Commits \$10 Million to Nuclear Fuel Reserve Proposal," IAEA Press Release, August 7, 2008 <http://www.iaea.org/NewsCenter/News/2008/uaecontribution.html>; "UAE Commitment Gives NTI/IAEA Fuel Bank Critical Momentum," NTI Press Release, August 7, 2008. [http://www.nti.org/c\\_press/release\\_UAE%20fuel%20bank%2080708.pdf](http://www.nti.org/c_press/release_UAE%20fuel%20bank%2080708.pdf)

<sup>74</sup> "Sam Nunn Applauds EU Contribution to IAEA Fuel Bank," NTI Press Release, December 10, 2008. [http://www.nti.org/c\\_press/statement\\_Nunn\\_EU\\_fuel\\_bank\\_121008.pdf](http://www.nti.org/c_press/statement_Nunn_EU_fuel_bank_121008.pdf)

<sup>75</sup> "Multinational Fuel Bank Reaches Key Milestone," IAEA Staff Report, March 6, 2009. <http://www.iaea.org/NewsCenter/News/2009/fbankmilestone.html>

<sup>76</sup> For more detailed treatment of these questions see, *New Framework for the Utilization of Nuclear Energy in the 21<sup>st</sup> Century: Assurances of Supply and Nonproliferation*, IAEA Special Event, Speech by Laura Holgate, September 19, 2006, at <http://www.nti.org>.

facilities were established. Proponents counter that these arrangements would be optional, but are meant to give countries alternatives to developing their own fuel cycle capabilities.<sup>77</sup> As of early 2010, the IAEA secretariat was engaged in discussing questions and concerns about the fuel bank proposal with member states.

The House (H.R. 1585) and Senate versions (S. 1547) of the National Defense Authorization Act for Fiscal Year 2008 both authorized \$50 million to be appropriated to the Department of Energy for the “International Atomic Energy Agency Nuclear Fuel Bank.” The conference report supports the establishment of a fuel bank and notes that “additional work will be required in order to provide appropriate guidance to the executive branch regarding criteria for access by foreign countries to any fuel bank established at the IAEA with materials or funds provided by the United States.”<sup>78</sup>

Both the House (H.R. 2641) and Senate (S. 1751) Energy and Water Appropriations bills for FY2008 recommended funding for an international nuclear fuel bank under the IAEA, and proposed making available \$100 million and \$50 million respectively. The Consolidated Appropriations Act for FY2008, which became P.L. 110-161 on December 26, 2007, provided that \$50 million should be available until expended for “the contribution of the United States to create a low-enriched uranium stockpile for an International Nuclear Fuel Bank supply of nuclear fuel for peaceful means under the International Atomic Energy Agency.” On August 4, 2008, the U.S. Secretary of Energy issued an official letter to the IAEA donating “nearly 50 million” to the international nuclear fuel bank.<sup>79</sup> This reflects a congressionally mandated rescission that was applied proportionally across the Department of Energy’s budget.<sup>80</sup>

### **Russian LEU Fuel Reserve, Angarsk**

The IAEA Board of Governors in November 2009 authorized the director general to sign an agreement with Russia establishing an LEU fuel reserve at Angarsk (GOV/2009/81). The fuel is to be available to a country facing a disruption of supply “unrelated to technical or commercial reasons.”<sup>81</sup> The reserve would contain about 120 MT of LEU in the form of UF<sub>6</sub> with an enrichment level ranging from 2 to 4.95% and would be under IAEA safeguards.<sup>82</sup> The Russian government would cover the cost of safeguards and all operating costs.

The Russian plan envisions that countries facing a fuel supply cut-off would apply to the IAEA to access the fuel reserve. The director general would assess whether the country meets the criteria for access. To qualify, the potential recipient state would have to be a non-nuclear-weapon state

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<sup>77</sup> Sylvia Westall, “Obama-backed nuclear fuel bank plan stalled at IAEA,” *Reuters*, June 18, 2009.

<sup>78</sup> H.Rept. 110-477 to accompany H.R. 1585.

<sup>79</sup> “U.S. Donates \$50 million for the IAEA International Nuclear Fuel Bank,” *NNSA Press Release*, August 4, 2008. <http://nnsa.energy.gov/news/2090.htm>

<sup>80</sup> Division C, Title III, Section 312 of the FY2008 Consolidated Appropriations Act rescinded 1.6 percent of discretionary budget authority for Congressionally directed projects, this includes the fuel bank. [http://www.whitehouse.gov/omb/legislative/fy08consolidated\\_reductions\\_01\\_25\\_08.pdf](http://www.whitehouse.gov/omb/legislative/fy08consolidated_reductions_01_25_08.pdf)

<sup>81</sup> “Board of Governors Approves Plan for Nuclear Fuel Bank: Russian Plan to Supply Low-Enriched Uranium,” IAEA Staff Report, November 27, 2009, <http://www.iaea.org/NewsCenter/News/2009/nuclfuelbank.html>

<sup>82</sup> “Development of the initiative of the Russian Federation to establish a reserve of low enriched uranium for the supply of LEU to the International Atomic Energy Agency for its member states,” Working Paper of the Russian Federation, Preparatory Committee for the 2010 NPT Review Conference, May 6, 2009, NPT/CONF.2010/PC.III/WP.25

member of the IAEA with a safeguards agreement in effect. To release the material, the IAEA would have to confirm that all nuclear material was accounted for in the state, there was no indication of diversion of material, and no safeguards issues were under review by the Board of Governors. If the criteria were met, the director general would ask Russia to release fuel to that country. The recipient country would pay market rates for the uranium. A country would not have to waive its right to develop its own fuel cycle capabilities in order to access the fuel reserve.

### **U.S. LEU Fuel Reserve: “Reliable Fuel Supply” Program**

In 2005, then-Secretary of Energy Samuel Bodman announced that 17.4 metric tons of U.S. surplus highly enriched uranium would be downblended to low-enriched uranium to be used as a U.S. fuel reserve. The goal of the U.S. reserve is to supply fuel in the event of a disruption unrelated to proliferation. Secretary Bodman described the U.S. reserve as supporting the “twin goals expanding the use of nuclear power and curbing nuclear proliferation,” and said its purpose was to “help countries to pursue nuclear power confidently, without the burden of producing their own fuel, while curbing the spread of sensitive technology.”<sup>83</sup>

The precise terms and conditions governing the release of the fuel and its potential recipients have not yet been determined. According to U.S. officials, the material designated for the U.S. reserve would be kept under national control, and not be part of the IAEA fuel bank.<sup>84</sup> Stringent U.S. requirements on U.S.-origin material, pursuant to the 1954 Atomic Energy Act (as amended), include safeguards in perpetuity, prior consent for enrichment and reprocessing, and the right of return should a non-nuclear-weapon state detonate a nuclear explosive device.<sup>85</sup>

The DOE’s Fissile Material Disposition program manages this initiative, called “Reliable Fuel Supply.” WesDyne International, LLC, and Nuclear Fuel Services, Inc., were awarded a contract in 2007 to downblend and store the material. Nuclear Fuel Services began downblending in December 2009 at its facility in Erwin, TN, and is expected to complete the work in 2010 or early 2011. The 17.4 MT of HEU is expected to produce about 290 MT of low enriched uranium. According to an NNSA press release, WesDyne will sell a “small fraction” of the resulting low enriched uranium on the market over a three to four year period to cover the project’s costs.<sup>86</sup> According to the FY2011 Department of Energy budget request, in 2009 the program completed all shipments of HEU for the Reliable Fuel Supply Initiative, and enough LEU has been downblended to date for multiple commercial reactor core reloads.

In addition to the downblending of 17.4 MT of HEU, an additional 12.1 MT is to be downblended to approximately 220 MT of LEU “to provide assurance of fuel supply to utilities participating in the MOX program for the disposition of surplus weapons plutonium.”<sup>87</sup> This tranche is expected to be downblended by 2012.

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<sup>83</sup> “DOE/NNSA Reliable Fuel Supply Gains Momentum,” NNSA Press Release, November 7, 2006.

<sup>84</sup> “News Analysis: The Growing Nuclear Fuel-Cycle Debate,” Arms Control Today, November 2006. Available at [http://www.armscontrol.org/act/2006\\_11/NAFuel.asp](http://www.armscontrol.org/act/2006_11/NAFuel.asp).

<sup>85</sup> See also CRS Report RS22937, *Nuclear Cooperation with Other Countries: A Primer*, by Paul K. Kerr and Mary Beth Nikitin.

<sup>86</sup> “NNSA Awards Contract for Reliable Fuel Supply Program,” NNSA Press Release, June 29, 2007.

<sup>87</sup> “NNSA Announces Contract to Downblend 12 Metric Tons of Surplus Highly Enriched Uranium,” NNSA Press Release, June 23, 2009.

LEU from both of the above HEU disposition programs will be stored until needed at Westinghouse's Columbia Fuel Fabrication Facility in Columbia, SC.

## **Assurance of Supply: Enrichment Services**

Proposals to assure supply and prevent the spread of enrichment technology have also included the creation of commercially based multinational uranium enrichment centers. The Russian Federation has made progress in establishing an International Uranium Enrichment Center (IUEC) at Angarsk. Germany has proposed an internationally owned and operated Multilateral Enrichment Sanctuary Program. Some point out that URENCO, a joint German, Dutch and British consortium, has demonstrated a multilateral commercial model for uranium enrichment since the 1970s. Some countries are concerned that giving support for multilateral-owned facilities would undermine their rights to nuclear technology for peaceful purposes under the NPT, and view the only solution to energy security as being an independent fuel cycle. However, as this may not be economically viable for most countries, multilateral solutions continue to be attractive.

### **International Uranium Enrichment Center (IUEC), Angarsk, Russia**

Russia has created a model International Uranium Enrichment Center (IUEC) at Angarsk (approximately 3,000 miles east of Moscow).<sup>88</sup> The Angarsk IUEC began operation on September 5, 2007. Kazakhstan was the first partner,<sup>89</sup> Armenia and Ukraine have also signed inter-governmental agreements to join IUEC. Finland, South Korea, and Belgium are negotiating their memberships in the IUEC.<sup>90</sup> As part of an open joint-stock company, IUEC participants would receive dividends from IUEC profits.

To join the Angarsk IUEC, countries must agree that the material be used for "nuclear energy production."<sup>91</sup> The IUEC is "chiefly oriented to States not developing uranium enrichment capabilities on their territory."<sup>92</sup> Russia now includes the IUEC on its list of Russian facilities that could be placed under IAEA safeguards. Additional documents for implementing safeguards at the facility are now under discussion. The safeguards would apply to the nuclear material at the facility.<sup>93</sup>

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<sup>88</sup> Anya Loukianova, "The International Uranium Enrichment Center at Angarsk: A Step Towards Assured Fuel Supply," NTI Issue Brief, updated November 2008, [http://www.nti.org/e\\_research/e3\\_93.html](http://www.nti.org/e_research/e3_93.html)

<sup>89</sup> A Russian-Kazakh joint venture Uranium Enrichment Center (distinct from the IUEC) is also located at Angarsk.

<sup>90</sup> Rosatom website, "Uranium Enrichment Division," accessed February 22, 2010. [http://www.rosatom.ru/en/energy\\_complex/uranium\\_enrichment/](http://www.rosatom.ru/en/energy_complex/uranium_enrichment/)

<sup>91</sup> "Russia's Angarsk international enrichment center open for business," *Nuclear Fuel*, September 24, 2007.

<sup>92</sup> "Communication received from the Resident Representative of the Russian Federation to the IAEA on the Establishment, Structure and Operation of the International Uranium Enrichment Centre," INFCIRC/708, June 8, 2007.

<sup>93</sup> Russia, as a nuclear weapon state under the NPT, has a voluntary safeguards agreement that allows, but does not require, inspections.



## **Germany's Multilateral Enrichment Sanctuary Project (MESP)**

Germany proposed in May 2007 that a new enrichment facility be built and placed under IAEA ownership in an extraterritorial area.<sup>94</sup> An independent management board or consortium would finance and run the plant on a commercial basis, but the IAEA would decide whether to supply enriched fuel according to nonproliferation criteria. Germany argues that this approach is advantageous since it does not prohibit uranium enrichment, but does provide a commercially viable, politically neutral option for fuel supply and could create competition on the world market by creating a new fuel service provider. With an economically viable option on neutral ground, it will be harder for states to justify starting their own enrichment program for commercial reasons. A proposal was presented to the IAEA Board of Governors in June 2009, and a draft MESP agreement (INFCIRC/765) submitted to the IAEA in July 2009. This concept has not yet been approved by the Board of Governors but is under active discussion.

## **Back-End Fuel Cycle Proposals**

Multilateral proposals for the end of the fuel cycle are less developed at this stage. On-site storage of spent fuel is most common, and some countries reprocess their spent fuel rods into mixed-oxide fuel. Multilateral solutions to the back-end issues are also motivated by the idea of preventing the further spread of reprocessing technology, which could be used for the separation of plutonium for weapons purposes. As with the debate over uranium enrichment technology, while reprocessing technology may be too expensive or technologically out of reach for many states at this stage, countries are hesitant to agree to multilateral approaches that may be interpreted as giving up their right to develop this technology for peaceful purposes. There are no multilateral reprocessing facilities now proposed.

Another proposal has been the establishment of an international spent fuel repository, perhaps in Russia. While Russian law allows for the import of waste, the government of Russia has not yet proposed such a facility, partly due to potential public opposition.

States also cooperate on joint research ventures on advanced and fast reactors such as the Generation IV International Forum (GIF) or IAEA's INPRO. A major U.S.-led initiative, the Global Nuclear Energy Partnership (GNEP) was meant to inspire international collaboration on developing a proliferation-resistance closed fuel cycle, discussed below.

## **Global Nuclear Energy Partnership (GNEP)**

In February 2006, U.S. Secretary of Energy Bodman announced the Global Nuclear Energy Partnership (GNEP), drawing together two of the former Bush Administration's policy goals: promotion of nuclear energy and nonproliferation. Recycling nuclear fuel to produce more energy and reduce waste and encouraging global prosperity were a few of DOE's stated aims for the program. GNEP built on DOE's Advanced Fuel Cycle Initiative (AFCI), a program that began in 2003 to develop and demonstrate spent fuel reprocessing/recycling technology. Today, GNEP continues in its international capacity, but funding for the domestic portions of the program are now only provided for fundamental research and development work. Efforts under AFCI to

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<sup>94</sup> "Safe Enrichment for All," *Handelsblatt* newspaper, May 2, 2007, in English at <https://www.diplo.de/diplo/en/Infoservice/Presse/Interview/2007/070502-Handelsblatt.html>.

develop large-scale reprocessing and recycling facilities have been halted by the Obama Administration, and the program has been renamed Fuel Cycle Research and Development.

The domestic component of GNEP originally focused on the future of nuclear energy in the United States: What kind of future reactors will be licensed, and how spent nuclear power reactor fuel will be handled. Existing commercial light water reactors were expected to continue as the predominant technology for at least the next two decades. Spent fuel from existing reactors was to be stored or retrievably emplaced at the planned Yucca Mountain, NV, repository, awaiting possible future reprocessing and recycling.

Reprocessing facilities were to use new technologies developed by AFCI to avoid separation of pure plutonium that could be used for weapons. However, there has been continuing controversy over how proliferation-resistant such processes might be. High-level waste from reprocessing (mostly fission products) would have gone to the Yucca Mountain repository, and the recycled plutonium and uranium was to be fabricated into fuel for an Advanced Burner Reactor, a fast reactor to be developed by DOE's Generation IV Nuclear Energy Systems Initiative. In the longer term, plutonium and other transuranics (elements heavier than uranium) in spent fuel were to be fabricated into new fuel for future fast reactors. Eventually, that fuel was to be continually recycled until all the transuranics were consumed, leaving the fission products to be disposed of in a geologic repository.

The international component of GNEP as originally envisioned was a consortium of nations with advanced nuclear technology that would provide fuel services and reactors to countries that "refrain" from fuel cycle activities, such as enrichment and reprocessing. It was essentially a fuel leasing approach, wherein the supplier would take responsibility for the final disposition of the spent fuel. This could mean taking back the spent fuel, but might also mean, according to DOE, that the supplier "would retain the responsibility to ensure that the material is secured, safeguarded and disposed of in a manner that meets shared nonproliferation policies."<sup>95</sup> While this describes the responsibility of the supplier, the vagueness of the language suggests that any number of solutions, including on-site storage, could be the outcome.

GNEP foresaw a system whereby supplier states would take back spent fuel, but many nations lack the political will to do so. Skeptics raised the question of whether the technology used in GNEP would have been a net gain for nonproliferation efforts, since the United States does not reprocess or re-use plutonium now. In their view, the "proliferation-resistance" of technologies under consideration must be assessed against the major alternative: disposal of sealed, intact fuel rods in a geologic repository. At the direction of the White House, Energy Secretary Steven Chu established the Blue Ribbon Commission on America's Nuclear Future on January 29, 2010, to recommend a new national strategy for managing spent nuclear fuel and high-level waste, including an examination of reprocessing and recycling options.

Much of the AFCI's research had focused on a separations technology called UREX+, in which uranium and other elements are chemically removed from dissolved spent fuel, leaving a mixture of plutonium and other highly radioactive elements. Proponents believe UREX+ is proliferation-resistant, because further purification would be required to make the plutonium useable for weapons and because its high radioactivity would make it difficult to divert or work with. In

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<sup>95</sup> DOE Global Nuclear Energy Partnership home page, at <http://www.gnep.energy.gov>.

contrast, conventional reprocessing using the PUREX process can produce weapons-useable plutonium that can be processed in unshielded gloveboxes.

However, critics see the potential nonproliferation benefits of UREX+ over PUREX as minimal. Richard Garwin suggested in testimony to Congress in 2006 that Urex+ fuel fails the proliferation-resistance test. Since it contains 90% plutonium, it could be far more attractive to divert than current spent fuel, which contains 1% plutonium. In other words, a terrorist would only have to reprocess 11 kg of Urex+ fuel to obtain roughly 10 kg of plutonium, in contrast to reprocessing 1,000 kg of highly radioactive spent fuel to get the same amount from light water reactor fuel.<sup>96</sup> Under the Obama Administration, the Fuel Cycle Research and Development program is no longer focusing on Urex processes but is instead conducting long-term research that could support a broad range of technology options, according to the DOE FY2011 budget justification.

Another nonproliferation-related concern about GNEP was how its implementation would have affected global stockpiles of separated plutonium. Frank Von Hippel pointed to costly plutonium recycling programs in the United Kingdom, Russia, and Japan, where separated plutonium stocks have accumulated to 250 tons, enough for 30,000 nuclear warheads. In Von Hippel's view, GNEP would have exchanged the safer on-site spent fuel storage at reactors for central storage of separated transuranics and high-level waste, cost many times more, and increased the global plutonium stockpile.<sup>97</sup>

A separate set of questions focused on how effective GNEP would have been in achieving its goals. By offering incentives for the back end of the fuel cycle, GNEP was designed to attract states to participate in the fuel supply assurances part of the framework. However, back-end fuel cycle assurances would require significant changes in policies and laws, as well as efforts to commercialize technologies. Further, it is far from clear that all suppliers would be able to offer the full range of fuel cycle assurances, raising the question of the relative competitiveness of suppliers. Critics did not necessarily argue that the overall vision of GNEP was misplaced, but were generally skeptical that its vision could be achieved, particularly in the timeframe proposed.

GNEP itself marked a departure from a U.S. policy of not encouraging the use of plutonium in civil nuclear fuel cycles. Supporters suggested that the U.S. policy developed in the late 1970s did not envision a recycling process that would not separate pure plutonium, and therefore questioned the underlying assumptions of that longstanding policy. Critics of GNEP have suggested that even though many nations did not agree with the United States in the 1970s on the dangers of having stockpiles of separated plutonium, the message that the United States conveyed was that reprocessing was unnecessary to reap the benefits of nuclear power and that GNEP conveyed the opposite message. Moreover, some critics pointed to the accumulation since the 1970s of separated plutonium as a particular threat, given the potential for terrorist interest in acquiring nuclear material.

An October 2007 study published by the National Academies of Science recommended that research and development activities for new reprocessing plants continue but be scaled back, with

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<sup>96</sup> Richard Garwin, "R&D Priorities for GNEP," Testimony to House Science Committee, April 6, 2006.

<sup>97</sup> Frank von Hippel, "GNEP and the U.S. Spent Fuel Problem," Briefing for Congressional Staff, March 10, 2006, at <http://www.princeton.edu/~globsec/publications/pdf/HouseBriefing10March06rev2.pdf>; Frank von Hippel, "Managing Spent Fuel in the United States: The Illogic of Reprocessing," International Panel on Fissile Materials, January 2007, at [http://www.fissilematerials.org/ipfm/site\\_down/ipfmresearchreport03.pdf](http://www.fissilematerials.org/ipfm/site_down/ipfmresearchreport03.pdf).

more time and peer review before commercial plants are built. It strongly criticized DOE's timeline for the program, saying that "achieving GNEP's goals are too early in development to justify DOE's accelerated schedule for construction of commercial facilities that would use these technologies."<sup>98</sup> Congress also expressed significant concerns about GNEP in recent years, particularly over the Bush Administration's ambitious schedule for developing fuel cycle demonstration facilities by FY2020.

The GNEP proposal attracted some international interest, at least among potential supplier states. Officials from China, France, Japan, Russia, and the United States met in Washington, DC, on May 21, 2007, to discuss GNEP and its goals. According to a joint statement issued after the meeting, "The participants believe in order to implement the GNEP without prejudice to other corresponding initiatives, a number of near- and long-term technical challenges must be met. They include development of advanced, more proliferation resistant fuel cycle approaches and reactor technologies that will preserve existing international market regulations."

In a formal presentation of GNEP principles, made September 16, 2007, in Vienna, Austria, participation was opened to all nations on a voluntary basis that agreed to internationally accepted standards for a safe, peaceful, and secure nuclear fuel cycle.<sup>99</sup> Sixteen countries joined the United States in signing the Statement of Principles for GNEP in September 2007, and the organization's website listed 25 "GNEP Partners" in June 2009.<sup>100</sup> The principles call for safe expansion of nuclear energy, enhanced nuclear safeguards, international supply frameworks, and development of fast reactors, "more proliferation resistant" nuclear power reactors, and spent fuel recycling technologies in facilities that do not separate pure plutonium. They did not call upon states to renounce or refrain from indigenous development of enrichment or reprocessing technologies but emphasized the goal of creating "a viable alternative to acquisition of sensitive fuel cycle technologies." It further emphasized that participants would not be giving up any rights to benefit from peaceful nuclear energy.

It may be difficult for the United States and others to define which states are suppliers and which are recipients. Informally, U.S. policy currently recognizes 10 states as having enrichment capability—the five nuclear weapon states (United States, United Kingdom, France, China, Russia) plus Japan, Argentina, Brazil, the Netherlands, and Germany. While Argentina has a plant (Pilcaniyeu) under safeguards, this plant has never operated commercially and it is doubtful that it will be cost-effective, since it uses outdated gaseous diffusion technology. Brazil's centrifuge enrichment plant at Resende is still in the early stages of commissioning and won't produce at a commercial scale for several years. States such as Australia, Canada, South Africa, and Ukraine have stated they would be interested in developing enrichment capability for export. On the reprocessing side, South Korea has expressed interest in becoming a GNEP supplier state through development of a pyroprocessing technique that does not separate plutonium from uranium. In the past, the United States for proliferation reasons has rejected requests from South Korea to reprocess U.S.-origin spent fuel.

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<sup>98</sup> "DOE's Spent Nuclear Fuel Reprocessing R&D Program Should Be Scaled Back; Boosted Efforts to Get New Nuclear Power Plants Online Needed," National Academies News Release, October 27, 2007, <http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=11998>.

<sup>99</sup> "Remarks as Prepared for Delivery by U.S. Secretary of Energy Samuel W. Bodman," 2<sup>nd</sup> Global Nuclear Energy Partnership Ministerial Opening Session Vienna, Austria, September 16, 2007.

<sup>100</sup> Global Nuclear Energy Partnership, <http://www.gneppartnership.org/index.htm>.

Despite the change in U.S. administrations, the international GNEP members have continued to meet. The fourth Global Nuclear Energy Steering Group meeting was held in Tokyo, Japan on April 7-8, 2009. GNEP's Infrastructure Development Working Group (IDWG) met during May 18-20, 2009, in Manchester, England, with 18 GNEP partner and observer countries and representatives from observer organizations participating, according to the GNEP website. The third GNEP Executive Committee Ministerial-Level Meeting was held in Beijing on October 23, 2009, and the IDWG met in Vienna, Austria, on December 9-10, 2009.

## **Supply-Side approaches**

### **Discussions in the Nuclear Suppliers Group (NSG)**

Current NSG Guidelines say supplier countries should exercise restraint in transferring any enrichment or reprocessing technologies. In the past several years, negotiations have been under way to specify criteria for such transfers. Since the 1970s, NSG members have adhered to an informal restriction on transferring enrichment, reprocessing, and heavy water technology to states outside the NSG. France first proposed an approach that would lay out a set of criteria that recipient states would first need to meet, including the following:

- Member of the NPT in full compliance.
- Comprehensive safeguards agreement and Additional Protocol in force.
- No breach of safeguards obligations, no IAEA Board of Governors decisions taken to address lack of confidence over peaceful intentions.
- Adherence to NSG Guidelines.
- Bilateral agreement with the supplier that includes assurances on non-explosive uses, effective safeguards in perpetuity, and retransfer.
- Commitment to apply international standards of physical protection.
- Commitment to IAEA safety standards.

The NSG also discussed including more subjective criteria in a decision to supply a state with fuel cycle technology such as general conditions of stability and security, potential negative impact on the stability and security of the recipient state, and whether there is a credible and coherent rationale for pursuing enrichment and reprocessing capability for civil nuclear power purposes.

No consensus has yet been reached on how to define these criteria, and a number of questions remain. For example, it is clear from these requirements that states outside the NPT—such as India, Pakistan, and Israel—would be prohibited from reprocessing and enrichment cooperation with NSG members. To add further complications, the nuclear cooperation agreement (so-called 123 Agreement) between the US and India provides consent in principle for India to reprocess U.S. spent fuel and agreement in principle to transfer enrichment and reprocessing-related technology to India, pursuant to an amendment to the agreement.<sup>101</sup> These two details suggest that India is a reprocessing technology holder, despite not having its reprocessing facilities under

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<sup>101</sup> See CRS Report RL33016, *U.S. Nuclear Cooperation with India: Issues for Congress*, by Paul K. Kerr.

comprehensive IAEA safeguards, and call into question criteria for distinguishing between states that should receive assistance and those that should not, particularly since India is neither a party to the NPT nor an NSG member.

The United States had objected to the criteria-based approach, favoring a moratorium, until spring 2008 when the Bush administration changed its policy. The U.S. reportedly would be in favor of establishing criteria if they included a requirement that uranium enrichment be exported only through a “black box” arrangement.<sup>102</sup> Canada objects to this, and negotiations are still underway.<sup>103</sup>

### **Group of Eight Nations (G-8)**

The Group of Eight (G-8) Nations has been the forum where joint policy statements have been made on this issue in recent years. From 2004-2007, the Group of Eight (G-8) Nations announced a year-long suspension of any such transfers at their annual summit meetings. The 2008 Summit declaration stated:

We agree that transfers of enrichment equipment, facilities and technology to any additional state in the next year will be subject to conditions that, at a minimum, do not permit or enable replication of the facilities; and where technically feasible reprocessing transfers to any additional state will be subject to those same conditions.<sup>104</sup>

Since in 2009 there still was no agreement on the transfer criteria in the NSG, the G-8 countries said that they would implement this policy on a national basis:

To reduce the proliferation risks associated with the spread of enrichment and reprocessing facilities, equipment and technology, we welcome the progress that continues to be made by the Nuclear Suppliers Group (NSG) on mechanisms to strengthen controls on transfers of such enrichment and reprocessing items and technology. While noting that the NSG has not yet reached consensus on this issue, we agree that the NSG discussions have yielded useful and constructive proposals contained in the NSG’s “clean text” developed at the 20 November 2008 Consultative Group meeting. Pending completion of work in the NSG, we agree to implement this text on a national basis in the next year. We urge the NSG to accelerate its work and swiftly reach consensus this year to allow for global implementation of a strengthened mechanism on transfers of enrichment and reprocessing facilities, equipment, and technology.<sup>105</sup>

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<sup>102</sup> “Black box” or turn-key plants would be built so that recipients would not be able to replicate the facilities, including sensitive components.

<sup>103</sup> Daniel Horner, Mark Hibbs, “G8 adopts interim measure on sensitive nuclear exports,” *Nucleonics Week*, July 17, 2008.

<sup>104</sup> See paragraph 66 of the Hokkaido Toyako G-8 Summit Leaders Declaration, July 8, 2008, [http://www.mofa.go.jp/policy/economy/summit/2008/doc/doc080714\\_\\_en.html](http://www.mofa.go.jp/policy/economy/summit/2008/doc/doc080714__en.html).

<sup>105</sup> See paragraph 8 of the L’Aquila G-8 Summit’s Statement on Nonproliferation, July 2009, [http://www.g8italia2009.it/static/G8\\_Allegato/2\\_LAquila\\_Statent\\_on\\_Non\\_proliferation.pdf](http://www.g8italia2009.it/static/G8_Allegato/2_LAquila_Statent_on_Non_proliferation.pdf)

## Comparison of Proposals

**Table 4** provides a comparison of the major proposals currently in circulation to restrict sensitive nuclear fuel technology development. The table is based on one created by Chaim Braun presented at the September 2006 IAEA conference on nuclear fuel supply assurances.<sup>106</sup>

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<sup>106</sup> The IAEA proposal is “Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report Submitted to the Director General of the International Atomic Energy Agency,” INFCIRC/640, International Atomic Energy Agency, February 22, 2006, p. 18. Available at <http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc640.pdf>. The Six-Country Concept is “Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel,” Proposal as sent to the IAEA from France, Germany, the Netherlands, Russia, Ireland, and the United States, May 31, 2006. Available at [http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2006/cn147\\_ConceptRA\\_NF.pdf](http://www-pub.iaea.org/MTCD/Meetings/PDFplus/2006/cn147_ConceptRA_NF.pdf).

**Table 4. Comparison of Major Proposals on Nuclear Fuel Services and Supply Assurances**

	<b>IAEA/INFCIRC/640</b>	<b>Putin Initiative</b>	<b>GNEP</b>	<b>Six Country Concept</b>	<b>World Nuclear Association</b>
Goals	Identify multilateral approaches across the fuel cycle; improve non-proliferation assurances without disrupting market mechanisms.	Establish international commercially operated nuclear fuel service centers in Russia, to include enrichment, education and training, and spent fuel management.	Enable expansion of nuclear power in the United States and around the world, promote nuclear nonproliferation goals, and help resolve nuclear waste disposal issues. Provide states with front-end and back-end services, to provide an alternative to the creation of national enrichment and reprocessing capabilities.	Create interim measures for front-end assurances.	Enhance supply security.
Target	Front-end and back-end services including uranium enrichment, fuel reprocessing, and disposal and storage of spent fuel. <sup>a</sup>	Supply of nuclear fuel and possibly other fuel cycle services.	Front- and back-end services. It could create new class of “reactor-only” states.	Supply of nuclear fuel.	Primarily fuel supply.
Methods	Reinforce commercial contracts with transparent supplier arrangements with government backing. International supply guarantees backed by fuel reserves.	Commercial, long-term contracts; recipients will have limited control over joint ventures. IAEA will be involved. <sup>b</sup>	Use existing enrichment and reprocessing services; develop more proliferation-resistant technology. Fuel supplier will be responsible for spent fuel disposition.	Level I: Market Level II: Fuel assurance mechanism at IAEA Level III: Mutual commercial back-up arrangements Level IV: Enriched uranium reserves	Level I: Market meets demand Level II: Standard back-up supply clause in enrichment contracts, with IAEA assurances Level III: Gov’t stocks of enriched uranium
IAEA Role	IAEA participates in administering supply guarantees, possibly as guarantor of service supplies with use of a fuel bank. Possible IAEA supervision of an international consortium for reprocessing services.	IAEA would ensure supply with fuel bank created by purchasing existing fuel stocks and placing them under its control (IAEA would receive new funding to do so).	IAEA would apply safeguards.	IAEA as broker. IAEA assesses status of safeguards agreements, safeguards implementation, safety, physical protection and whether a country is pursuing sensitive fuel cycle activities.	IAEA would approve “triggering” mechanism for supply back-up. IAEA could manage enriched uranium reserve.



	IAEA/INFCIRC/640	Putin Initiative	GNEP	Six Country Concept	World Nuclear Association
Eligibility	Recipient countries would renounce the construction and operation of sensitive fuel cycle facilities and accept safeguards of the highest current standards including comprehensive safeguards and the Additional Protocol.	Equal access, but prerequisite is compliance with the nonproliferation regime. Potential provider states could include Australia and Canada.	No requirements now (versus initial requirement for recipient states to forego enrichment and reprocessing).	IAEA-approved states that are in good NPT standing. States that develop national capabilities will not be eligible.	IAEA-approved states that meet all NPT obligations.
Role of Industry	Managing, operating centers.	Performing fuel services at designated center.	Performing fuel services, but not necessarily coordinated.	Perform enrichment contracts; identified need to address back-end of fuel cycle.	Perform enrichment contracts. No new capabilities required.
Potential Concerns	No mechanism specified for assessing state's nonproliferation record.	Incentives not specified, as well as compliance with nonproliferation regime. Unclear how commitments to forgo sensitive fuel cycle activities will be incorporated into contracts.	Lack of political will to take back spent fuel. Concerns about gains for nonproliferation, if the United States was not reprocessing to begin with.	Incentives may be insufficient.	Incentives may be insufficient. How to determine price on enriched uranium reserves, if they are required.

a. INFCIRC/640, p. 103.

b. "Questions Abound on Proposals by Bush, Putin on Fuel Centers," *Nuclear Fuel*, March 13, 2006, vol. 31, no. 3.

## Prospects for Implementing Fuel Assurance Mechanisms

Proposals to provide an international and institutional framework for peaceful nuclear activities have abounded since the 1940s, but few have been implemented. The U.S.-sponsored Baruch Plan introduced at the United Nations in 1946 recommended establishing an international agency with managerial control or ownership of all atomic energy activities. The International Atomic Energy Agency, established in 1957, emerged as a paler version of what was suggested in the Baruch Plan, but still retains authorities in its statute to store fissile material.

Concern about proliferation led to a flurry of proposals in the 1970s and 1980s as the United States and others convened groups to study the issues.<sup>107</sup> One idea studied in the mid-1970s was regional nuclear fuel cycle centers, focused on reprocessing technologies. Several factors contributed to its lack of success, despite support by the U.S. Congress: low uranium prices (making plutonium recovery relatively unattractive), a slump in the nuclear industry in the late 1970s and early 1980s, and U.S. opposition to reprocessing from the late 1970s. Member states of the IAEA also convened the International Fuel Cycle Evaluation project, which involved 60 countries and international organizations. INFCE working group reports suggested establishing a multi-tiered assurance of supply mechanism similar to the one proposed by the Six Country Concept in 2006. States also studied international plutonium storage in the late 1970s and early 1980s, but could not agree on how to define excess material or the requirements for releasing materials.

As in the past, the success of current proposals may depend on whether nuclear energy is truly revived not just in the United States, but globally. That revival will likely depend on significant support for nuclear energy in the form of policy, price supports, and incentives. Factors that may help improve the position of nuclear energy against alternative sources of electricity include higher prices for other sources (natural gas and coal through a carbon tax or other restrictions), improved reactor designs to reduce capital costs, regulatory improvements, and waste disposal solutions.

The willingness of fuel recipient states to participate in international enrichment centers rather than develop indigenous enrichment capabilities, and confidence in fuel supply assurance mechanisms such as an international fuel bank, will largely determine the success of the overall policy goal—to prevent further spread of enrichment and reprocessing technologies. So far, proposals addressing this challenge have originated in the supplier states, with many recipient states continuing to voice concern that their right to peaceful nuclear energy technology under the NPT is in jeopardy. Increasingly, however, participation is being presented as a market-based decision by countries to refrain, at least for the present, from developing their own fuel enrichment programs.

Another factor that will shape the success of these proposals is the possible addition of other incentives. Simply making nuclear energy cost-effective may not induce countries to forgo indigenous enrichment and reprocessing. Such decisions may require other incentives, perhaps

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<sup>107</sup> For an analysis of these past proposals, see Lawrence Scheinman, “Equal Opportunity: Historical Challenges and Future Prospects of the Nuclear Fuel Cycle,” *Arms Control Today*, May 2007.

even outside the nuclear realm, to make them palatable. The experience of Iran may be instructive here. Russia's offer to provide assured enrichment services on Russian soil has gone nowhere; instead, other, broader trade incentives may be necessary. While the case of Iran may illustrate the extreme end of the spectrum, in terms of a country determined to develop a capability for a weapons program, non-nuclear-weapon states will clearly take notice of how a solution develops for Iran.

## Issues for Congress

Congress would have a considerable role in at least four areas of oversight related to fuel cycle proposals. The first is providing funding and oversight of U.S. domestic programs related to expanding nuclear energy in the United States. Key among these programs are nuclear research and development programs and federal incentives for building new commercial reactors.<sup>108</sup>

The second area is policy direction and/or funding for international measures to assure supply. What guarantees should the United States insist upon in exchange for helping provide fuel assurances? Although the Six Country Concept contains an option for a fuel bank, it would not require participants to forswear enrichment and reprocessing.

A third set of policy issues may arise in the context of implementing the international component of GNEP. As referenced above, in the original policy documents, GNEP participant states would "agree to refrain from fuel cycle initiatives." However, in recent ministerial meetings, this language was no longer used and participation was opened to all. This is most likely meant to increase participation in the initiative by emphasizing that GNEP is not asking states to give up rights to peaceful nuclear technology.

Some observers believe that further restrictions on non-nuclear-weapon states party to the NPT are untenable in the absence of substantial disarmament commitments by nuclear weapon states. In particular, a January 4, 2007, *Wall Street Journal* op-ed by George Shultz, Bill Perry, Henry Kissinger, and Sam Nunn, entitled "A World Free of Nuclear Weapons," noted that non-nuclear-weapon states have grown increasingly skeptical of the sincerity of nuclear weapon states in this regard. Some observers have asserted that non-nuclear-weapon states will not tolerate limits on NPT Article IV rights (right to pursue peaceful uses of nuclear energy) without progress under Article VI of the NPT (disarmament). Amending the NPT is seen by most observers as unattainable. President Obama called for the eventual elimination of nuclear weapons in a speech in the Czech Republic on April 5, 2009.

The IAEA experts group report, INFCIRC/640, did point to the political usefulness of achieving a ban on producing fissile material for nuclear weapons (known as fissile material production cutoff treaty, or FMCT) to provide more balance between the obligations of nuclear and non-nuclear-weapon states. Obama administration officials have indicated that they will pursue negotiations on a fissile material cut-off treaty that includes verification provisions. Ultimately, any such treaty would require Senate advice and consent to ratification.

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<sup>108</sup> See CRS Report RL33558, *Nuclear Energy Policy*, by Mark Holt.

A fourth area in which Congress plays a key role would be in the approval of nuclear cooperation agreements.<sup>109</sup> In some cases, the United States may seek additional reassurances regarding fuel cycle facilities during negotiations of civilian nuclear cooperation agreements. This was a topic of controversy during the approval process for the civilian nuclear cooperation agreement with India in September 2008.<sup>110</sup> A civilian cooperation agreement with the United Arab Emirates was submitted to the 111<sup>th</sup> Congress for consideration on May 21, 2009,<sup>111</sup> and it took effect December 17, 2009. In April 2009, the UAE had signed a memorandum of understanding with the United States saying it would forgo “domestic enrichment and reprocessing capabilities in favor of long-term commitments of the secure external supply of nuclear fuel.” In addition, the nuclear cooperation agreement’s text itself states that the United States can end nuclear cooperation with the UAE if it acquires enrichment or reprocessing facilities.

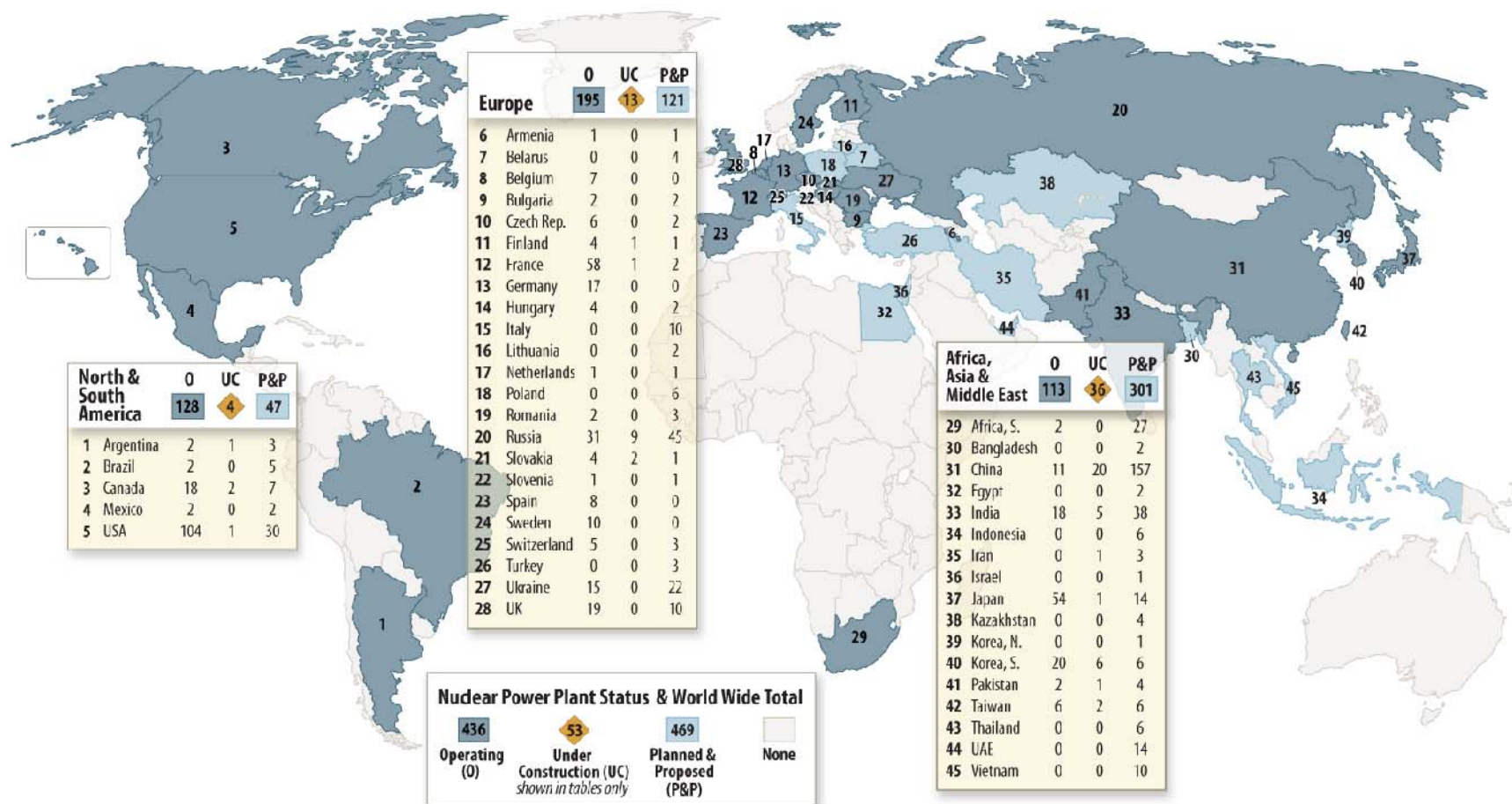
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<sup>109</sup> See CRS Report RS22937, *Nuclear Cooperation with Other Countries: A Primer*, by Paul K. Kerr and Mary Beth Nikitin.

<sup>110</sup> CRS Report RL33016, *U.S. Nuclear Cooperation with India: Issues for Congress*, by Paul K. Kerr

<sup>111</sup> CRS Report R40344, *The United Arab Emirates Nuclear Program and Proposed U.S. Nuclear Cooperation*, by Christopher M. Blanchard and Paul K. Kerr.

Figure 2. World Wide Nuclear Power Plants Operating, Under Construction, and Planned



Source: World Nuclear Association, <http://www.world-nuclear.org/info/reactors.html>

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